

Tronox Navajo Area Uranium Mines Northern Abandoned Uranium Mine Region

Draft

Brodie 1 Mine

Alternative Analysis Memorandum



September 30, 2021



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Brodie 1 Mine Alternative Analysis Memorandum

Response, Assessment, and Evaluation Services

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Submitted by

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ACRONYMS AND ABBREVIATIONS

§	Section
AAM	Alternative Analysis Memorandum
ABA	Acid-base accounting
AEA	Atomic Energy Act
ARAR	Applicable or relevant and appropriate requirement
ARARs Technical Memorandum	“Navajo Nation Abandoned Uranium Mines Applicable or Relevant and Appropriate Requirements Technical Memorandum”
AUM	Abandoned uranium mine
bgs	Below ground surface
BMP	Best management practice
BTV	Background threshold value
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	<i>Code of Federal Regulations</i>
COC	Contaminant of concern
COEC	Contaminant of ecological concern
COPC	Contaminant of potential concern
COPEC	Contaminant of potential ecological concern
cpm	Counts per minute
CSM	Conceptual site model
DL	Discrimination limit
EE/CA	Engineering evaluation/cost analysis
EPC	Exposure point concentration
ERA	Ecological risk assessment
ET	Evapotranspiration
EU	Exposure unit
HDPE	High density polyethylene
HELP	Hydrologic evaluation of landfill performance
HHRA	Human health risk assessment
HQ	Hazard quotient
Kerr-McGee	Kerr-McGee Corporation
LiDAR	Light detection and ranging
LLRW	Low-level radioactive waste
LOEC	Lowest observed effects concentration



ACRONYMS AND ABBREVIATIONS (CONTINUED)

MARSSIM	<i>Multi-Agency Radiation Survey and Site Investigation Manual</i>
NAMLRD	Navajo Nation Abandoned Mine Lands Reclamation Department
NAUM	Navajo area uranium mines
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
Neptune	Neptune and Company, Inc.
NNEPA	Navajo Nation Environmental Protection Agency
NORM	Naturally occurring radioactive materials
NRC	Nuclear Regulatory Commission
NTUA	Navajo Tribal Utility Authority
O&M	Operation and maintenance
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
pCi/g	Picocurie per gram
pCi/m ² -sec	Picocurie per meter squared per second
Ra-226	Radium-226
RAG	Removal action goal
RAO	Removal action objective
RBSL	Risk-based screening level
RCRA	Resource Conservation and Recovery Act
Risk Assessment CSM	“Navajo Nation-Wide Abandoned Uranium Mines Risk Assessment Conceptual Site Model and Methodology”
RME	Reasonable maximum exposure
RSE	Removal site evaluation
SPLP	Synthetic precipitation leaching procedure
SU	Survey unit
SWPPP	Stormwater pollution prevention plan
TBC	To Be Considered
Technology Technical Memorandum	“Navajo Nation Abandoned Uranium Mines Technology Evaluation and Alternative Development Technical Memorandum”
TENORM	Technologically enhanced naturally occurring radioactive material
Tetra Tech	Tetra Tech, Inc.
TSG	TerraSpectra Geomatics

**ACRONYMS AND ABBREVIATIONS (CONTINUED)**

U ₃ O ₈	Triuranium octoxide
UCL95	95 percent upper confidence limit
UMTRCA	Uranium Mill Tailings Radiation Control Act
USEPA	U.S. Environmental Protection Agency
UTL-95-95	95 percent upper tolerance limit with 95 percent coverage
V ₂ O ₅	Vanadium pentoxide
VCA	Vanadium Corporation of America
Weston	Weston Solutions, Inc.
XRF	X-ray fluorescence



1.0 EXECUTIVE SUMMARY

1.1 PURPOSE OF THE ALTERNATIVES ANALYSIS MEMORANDUM

This Alternatives Analysis Memorandum (AAM) recognizes that under the Fundamental Laws of the Diné, the four problem-solving stages are (1) thinking (*nitsahakees*), (2) planning (*nahat'a*), (3) implementation (*lina/jina'*), and (4) eventual results (*sihasin*). The stages of the problem-solving process flow in a circular direction with the first (*nitsahakees*) and second (*nahat'a*) stages represented in this AAM (as shown on [Figure 1](#)). This AAM develops (*nitsahakees*) and evaluates (*nahat'a*) alternatives for addressing the risks to human health and the environment associated with the Brodie 1 Mine (site) mine waste and contaminated soils in the context of the Fundamental Laws of the Diné and in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). This AAM also presents the results of the thinking (*nitsahakees*) and planning (*nahat'a*) stages of the Fundamental Laws of the Diné for the Brodie 1 Mine.

Input from the Navajo Nation and Sweetwater community will be considered in the selection of a preferred alternative; therefore, this AAM does not identify a preferred alternative. The last two stages of problem solving, the implementation (*lina/jina'*) and results (*sihasin*), will occur after the U.S. Environmental Protection Agency (USEPA) solicits Navajo input on the AAM, presents the preferred alternative in the future engineering evaluation/cost analysis (EE/CA), and selects a response action in an action memorandum for the site. At that point, the response action will go through engineering design and implementation to achieve the removal action objectives (RAO) (*sihasin*)

1.2 NITSAHAKEES - SITE CHARACTERIZATION

The **Brodie 1 Mine** is located near Red Mesa, Arizona, in the Sweetwater Chapter of the Navajo Nation, approximately 38 miles northwest of Shiprock, New Mexico ([Figure 2](#)). The Brodie 1 Mine is a former underground uranium-vanadium mine in the Tse Tah region and is administered by the Sweetwater Chapter of the Navajo Nation. The mine produced 5 tons of ore in 1951. The Navajo Nation Abandoned Mine Lands Reclamation Department (NAMLRD) excavated and consolidated waste from the waste pile (reclaimed) into the onsite burial cell and closed the mine portal in 1999. The features at the site include **one reclaimed waste pile, one unreclaimed waste pile, one burial cell, and one closed portal**. No removal actions have been conducted at the Brodie 1 Mine.

The agricultural and residential community of Red Mesa, Arizona, located 6 miles northwest of the site, is the nearest population center. The Brodie 1 Mine is documented to have human and wildlife visitation and eight residences are located within 1 mile of the site. The likely **future land use at the site is Kee'da'whíí tééh (full-time Navajo residential)**, including cultivation of homegrown produce, plant gathering, and livestock grazing. The flat terrain upslope and downslope of the site provides potential locations for the siting of houses, hogans, corrals, or stock-loading ramps.

The nature and extent of contamination at the Brodie 1 Mine was characterized during the Removal Site Investigation (RSE) completed in October 2018 **Most of the waste at the site is**

associated with the burial cell and unreclaimed waste pile. Areas with contamination outside the waste rock piles and burial cell are present because mining-related activities exposed naturally occurring mineralized rock on the slopes at the mine and natural erosion exposed the ore zone on the cliff and in the upslope area.

Tetra Tech, Inc. (Tetra Tech) completed a human health risk assessment (HHRA) and an ecological risk assessment (ERA) to evaluate the potential risk posed to human and ecological health by mine-related contamination. The results of the HHRA and ERA are then used to assist in making cleanup decisions for the Brodie 1 Mine and the Tse Tah West Wash through the EE/CA process. The risk assessments evaluate current and future human health risk under Navajo-specific reasonable maximum exposure (RME) scenarios and regional ecological risk.

The results of the HHRA and ERA indicate that risks are present at the Brodie 1 Mine for human and ecological receptors. At the site, radium-226 (Ra-226), uranium, and vanadium are contaminants of concern (COC), and vanadium is a contaminant of ecological concern (COEC). No human health or ecological risks are present in the downgradient Tse Tah West Wash. Removal action is recommended for contamination associated with COCs and COECs at the Brodie 1 Mine.

Human health and ecological removal action goals (RAG) were derived for COCs and COECs. The RAG is the lesser of the human health and the ecological risk-based screening levels (RBSL). When one or both RBSLs are less than the background threshold value (BTV) the RAG becomes the BTV. For purposes of this AAM, the BTV is used to represent background for delineating contaminated areas.

Multiple lines of evidence were used to develop the removal action extent at the Brodie 1 Mine, including the extent of Ra-226 in surface soil and sediment, extent of contamination of other COCs and COECs not collocated with Ra-226, surface and subsurface waste areas, transport pathways, disturbed mineralized areas, accessibility considerations, and risk management considerations. The removal action extent covers about 9,700 square feet of land at the site. **A total of 1,310 cubic yards of mine waste and contaminated soil will be addressed by removal action.**

1.3 NAHAT'A - REMOVAL ACTION OBJECTIVES

The first step in developing removal alternatives is to establish RAOs. Taking current and potential future land use and Navajo cultural considerations into account, the RAOs are to:

- Prevent exposure to soil with contaminants that would pose an unacceptable risk to human health with residential use and traditional Diné lifeways outside of any potential capped area
- Prevent exposure to soil with contaminants that would pose an unacceptable risk to human health with traditional Diné lifeways on any potential capped area, which may include exposures that occur during activities such as livestock grazing, hunting, and plant gathering and use.
- Prevent exposure to soil with contaminants that would pose an unacceptable risk to plants, animals, and other ecological receptors



- Prevent migration of contaminants to surface water or groundwater that pose an unacceptable risk to human health
- Prevent offsite migration of contaminants above background concentrations and at concentrations that could pose a risk to human health or the environment

The scope of the removal action will be to address all solid media contamination at the Brodie 1 Mine and to be the final action for solid media at the site.

1.4 NAHAT'A - IDENTIFICATION OF REMOVAL ACTION ALTERNATIVES

The following removal action alternatives were developed and evaluated as part of this AAM:

- **Alternative 1: No Action (this must always be evaluated)** – No treatment or removal action would occur at the site. Consequently, all threats would remain unchanged. Mine waste and contaminated soils would continue to threaten human and ecological receptors. Gamma radiation and physical hazards would still be present.
- **Alternative 2: Consolidation and Capping** – Attains RAOs by excavating the burial cell contents, residual waste rock, and contaminated soils; consolidating the waste in a new burial cell; and capping the burial cell. An evapotranspiration (ET) cap will be used that is protective and will prevent contaminant migration. The burial cell will be maintained for 1,000 years.
- **Alternative 3: Excavation, Transport, and Disposal in On-Navajo Nation Regional Repository** - Attains RAOs by excavating the burial cell contents, residual waste rock, and contaminated soils; hauling the waste 6 miles to a nearby on-Navajo Nation regional repository; consolidating the waste in the repository; and capping the repository. An ET cap will be used and is protective and will prevent contaminant migration. The repository will be maintained for 1,000 years.
- **Alternative 4: Excavation, Off-Navajo Nation Transport, and Disposal at White Mesa Mill** - Attains RAOs by excavating the burial cell contents, residual waste rock, and contaminated soils; hauling the waste 63 miles to the White Mesa Mill near Blanding, Utah, for uranium recovery; and disposing of the mill tailings in a tailing disposal facility. Off-Navajo Nation disposal is protective and does not require long-term maintenance.
- **Alternative 5: Excavation, Off-Navajo Nation Transport, and Disposal at Hazardous Waste or Low-Level Radioactive Waste (LLRW) Facility** - Attains RAOs by excavating the burial cell contents, residual waste rock, and contaminated soils; and hauling the waste 565 miles to and disposing of the waste in the Clean Harbors Deer Trail, Colorado, Resource Conservation and Recovery Act (RCRA) hazardous waste disposal facility. Off-Navajo Nation disposal is protective and does not require long-term maintenance.

Cleanup alternatives involving the physical removal of mine waste and the consolidation and capping of waste will address recontouring and revegetation of land to match natural landscape and removal of temporary access and mining-related roads.

1.5 NAHAT'A - ANALYSIS OF REMOVAL ACTION ALTERNATIVES

The removal action alternatives were evaluated individually and in relation to each other using three broad criteria: effectiveness, implementability, and cost. An overview of the comparative analysis is presented below.

Removal Action Alternative		Effectiveness	Implementability	Estimated Costs
1	No Action	Very Poor	Very Good	Very Good (\$ 0)
2	Consolidation and Capping	Good	Very Good	Poor (\$ 3.1 Million)
3	Excavation, Transport, and Disposal in On-Navajo Nation Regional Repository	Average	Good	Average (\$ 2.7 Million)
4	Excavation, Off-Navajo Nation Transport, and Disposal at White Mesa Mill	Good	Good	Good (\$ 2.3 Million)
5	Excavation, Waste Transfer, Off-Navajo Nation Transport, and Disposal at Hazardous Waste or LLRW Facility	Average	Very Good	Average (\$ 2.8 Million)

Notes:

Bold indicates the highest rating in the category.

LLRW Low-level radioactive waste

This AAM was prepared without a preferred removal action alternative to provide an opportunity for tribal and public input on the removal action alternatives development and evaluation process. Following tribal and public input, a final EE/CA will be prepared, including a recommended removal action alternative for public comment.

2.0 NITSAHAKEES - SITE CHARACTERIZATION

This section presents the site description and background; previous reclamation and removal actions; previous site investigations; source, nature, and extent of contamination; risk assessment, and removal action extent.

2.1 SITE DESCRIPTION AND BACKGROUND

The Brodie 1 Mine contains waste rock and other mine waste and debris in the waste piles beneath the portal and in the adjacent burial cell. [Appendix A](#) contains site images. The following subsections describe the site location, type of mine and operational status, regulatory history, site features and landscape, geology and hydrology, land use and populations, sensitive ecosystems and habitat, and meteorology and climate.

2.1.1 Site Location

The Brodie 1 Mine is located within the Northern Abandoned Uranium Mine (AUM) Region of the Navajo Nation in Tse Tah mining district. The Brodie 1 Mine is northwest of the Carrizo Mountains, 3.7 miles from the Red Mesa Four Corners Regional Medical Center, and 5.5 miles from the Sweetwater Chapter House ([Figure 1](#) and [Figure 3](#)) at 36.905973 degrees latitude and -109.352583 degrees longitude within Apache County, Arizona, within the Sweetwater Chapter of the Navajo Nation. The elevation is approximately 5,724 feet above mean sea level. The closest Tronox AUM to the site is the Block K Mine to the east ([Figure 3](#)). The closest non-Tronox AUMs are NA-0928 and Silentman 1, also located east of the site.

The Brodie 1 Mine is accessed by traveling 15.5 miles west of Teec Nos Pos on Highway 160 and then turning south for approximately 2 miles on Indian Route 35. The site is approximately 0.5 mile west from Indian Route 35. The site is relatively easy to access by foot, but a small sandstone ledge above the mine precludes access by vehicle from the east ([Figure 3](#)) (Appendix K of the “Northern Agency Tronox Mines Removal Site Evaluation [RSE] Report” [Tetra Tech 2019]).

2.1.2 Type of Mine and Operational Status

The Brodie 1 Mine was accessed by an adit and developed using underground room-and-pillar mining techniques to extract lenticular ore bodies with uranium at a concentration of 1.37 percent triuranium octoxide (U_3O_8) and vanadium at a concentration of 3.20 percent vanadium pentoxide (V_2O_5). The host rock is a fine to medium sandstone cemented with calcium carbonate. Whether the pillars were salvaged and the rooms blasted closed is unknown. Depending on the mining methods used, land shifting, subsidence, fissures, and cracks within the mine are possible.

The Brodie 1 Mine began operation in 1951 and was transferred in 1962 to Kerr-McGee Corporation (Kerr-McGee), a predecessor to Tronox (Roux Associates 2011). Kerr-McGee transferred Mike Brodie’s mining permit to the Vanadium Corporation of America (VCA) with the sale of the Shiprock Mill in 1963 (VCA 1963). The mine produced 5.5 tons of ore containing 150 pounds of U_3O_8 and 350 pounds of V_2O_5 (Chenoweth 1985).

Kerr-McGee and VCA did not complete reclamation of the mine or waste piles. Site features and reclamation features are shown on [Figure 5](#).

2.1.3 Regulatory History

The Brodie 1 Mine is part of the 2015 Kerr-McGee/Tronox Settlement Agreement (*In re Tronox Inc.*, No. 09-10156 (Bankr. S.D.N.Y. Nov. 23, 2010)). The previous investigations of the site completed since 1989 are summarized in [Section 2.3](#). In 1999 under the NA-0507 Carrizo 1 reclamation project, the NAMLRD closed the portal, partially excavated a waste rock pile, and placed the waste in an onsite burial cell. Detailed information regarding previous reclamation and removal actions are provided in [Section 2.2](#).

2.1.4 Site Features and Landscape

The Brodie 1 Mine survey area boundary is 1.3 acres and is not contiguous with any other AUMs. Steep sandstone ledges approximately 20 to 25 feet tall bisect the site from north to south as shown on [Figure 6](#). Above and below the sandstone ledges, the site is relatively flat. There is a portal midway on the sandstone ledge with mine waste in two commingled waste piles below the portal. One onsite burial cell is located north of the waste piles. A drainage swale originates on the upper portion of the site west of the portal and runs directly through the unreclaimed waste pile along the western portion of the site and into the Tse Tah West Wash. The Tse Tah West Wash runs southwest to northeast and is located north and downgradient of the site. In addition, a 60-foot-long diversion berm is located above the portal on the west end of the site. The site land has slopes between 0 and 38.0 degrees. No nearby ridges provide opportunities for sheep camps. Based on light detection and ranging (LiDAR) data from 2019, the site has 1 percent vegetation coverage. [Appendix A](#) contains site photographs of the vegetation.

The vegetation communities on the site include Grassland Shrub and Slickrock-Rimrock. The Grassland Shrub Community consists of equal coverage of grasses and shrubs (Clifford 2015). The shrubs are dominated by broom snakeweed (*Gutierrezia sarothrae*), Bigelow's rabbitbrush (*Chrysothamnus nauseosus* var. *bigelovii*), slender buckwheat (*Eriogonum microthecum*), winterfat (*Ceratoides lanata*), and fourwing saltbush (*Atriplex canescens*), and there are a wide diversity of grasses present in the community. The Slickrock-Rimrock Community includes slickrock, rimrock, cliffs, ledges, and talus habitats and the plant composition can vary regionally depending on host stratigraphic rock units. Co-dominant shrubs, such as sagebrush (*Artemisia tridentata*, *Artemisia frigida*, and *Artemisia nova*), and associate herbaceous forbs, such as (*Penstemon pachyphyllus*) and Indian paintbrush (*Castilleja* sp.), make up the vegetation in this community (Clifford 2015). This community occurs on exposed massive-bedded sandstone along uplifted hogback ridges and mesa tops. Two rare plants can occur in this community: MacDougal's falsecarrot (*Aletes macdougalii*) and Mathew's ballhead gilia (*Ipomopsis congesta* var. *mathewsii*) (Clifford 2015).

Site features include one portal, two commingled waste piles, and one burial cell ([Figure 5](#)). Reclamation of some of these features occurred during the NA-0507 Carrizo 1 NAMLRD reclamation project and are described in [Section 2.2](#).

Table 1 presents the reclamation status, description, and dimensions for each site feature. Site features include:

- Portal 41 was closed and stabilized with a cement block bulkhead under a NAMLRD project. Underground workings have not been mapped.
- Waste Pile 41 was partially removed during the NA-0507 Carrizo 1 NAMLRD reclamation project (see [Section 2.2](#)). Waste Pile 41 covers 0.015 acre.
- Waste Pile M1 was mapped during the 2018 RSE investigation as unreclaimed. Waste Pile M1 covers 0.05 acre and encompasses most of Waste Pile 41.

The unnamed tributary to the Tse Tah West Wash cuts through Waste Pile M1 and flows north and is located 10.2 miles from the junction of the Tse Tah West Wash and Tse Tah Wash.

Part of the access road to the site was eliminated at the conclusion of the NA-0507 Carrizo 1 NAMLRD reclamation project; however, the remainder of the access road leading to residential structures was left unreclaimed (see [Section 2.2](#)).

An archaeological survey completed at the site before the RSE investigation identified a culturally sensitive area in the northeast corner of the site survey area, which was excluded from the RSE investigation (Tetra Tech 2019). Activities in surrounding areas and any new access routes would require additional clearance before removal actions.

2.1.5 Geology and Hydrology

The geology of the Tse Tah region consists of sedimentary strata of the Mesozoic era folded about the Toh Atin Anticline and exposed in broad incised valleys filled with Quaternary alluvium. The Brodie 1 Mine is located on a shallow slope northwest of the Carrizo Mountains and straddles a northeast-trending cliff face. Site hydrology and geology are presented on [Figure 6](#) and [Figure 7](#). The geological unit underlying the Tse Tah West Wash downgradient of the site is Quaternary alluvium.

The Salt Wash Member of the lower Morrison Formation and the San Rafael Group sandstones outcrop near the site. The Salt Wash Member of the Morrison Formation consists of interbedded mudstones and sandstones. Mining and exploration records indicate that most uranium and vanadium mineralization in the northwest Carrizo Mountains occurred within the bottom 40 feet of Salt Wash Member of the Morrison Formation ([Figure 7](#)) (Chenoweth 1995). The mine was located through mapping outcrops of naturally occurring uranium ore. The mine removed ore from a sandstone bed within Salt Wash Member of the Morrison Formation and is underlain by less competent fine sandstone and mudstone. San Rafael Group outcrops north of the site.

The Tse Tah region comprises sedimentary and volcanic rocks with the sedimentary rocks consisting of stacked sandstone and limestone units generally separated from one another by low-permeability shales and siltstones (Arizona Department of Water Resources 2009). Regional groundwater movement is to the northwest within the Wingate Sandstone Formation of the C aquifer. The C aquifer is the only regional aquifer present since the host rock for the D and N aquifers has been removed by erosion. Seven wells are located within 1.2 to 4 miles of the site and screened to depths of 435 to 1,092 feet below the lower Morrison Formation in either the

Summerville Formation or Wingate Sandstone Formation as shown on [Figure 8](#) (Neptune and Company, Inc. [Neptune] and TerraSpectra Geomatics [TSG] 2018). Five wells are used for livestock purposes; the uses of the other two wells are unknown.

The site is located within the Lower San Juan-Four Corners Watershed (Hydrologic Unit Code 14080201). A small ephemeral drainage begins upgradient of the site and flows over the sandstone ledge through a waste pile and into a deeper incised channel. The drainage then crosses an alluvial plain where the water infiltrates. During high flow events, the water enters into a much larger wash downstream called the Tse Tah West Wash. The Tse Tah West Wash flows into the Tse Tah drainage and then into the Lower San Juan River. No mining-influenced water was observed to discharge from the mine portal and no evidence that water historically drains from the adit was found.

In the nearby Teec Nos Pos and Red Mesa communities, 730 Navajo Tribal Utility Authority (NTUA) (2019) service connections provide drinking water that originate in Farmington, New Mexico. Whether local residents closest to the site use groundwater or NTUA service for potable water is unknown.

2.1.6 Land Use and Populations

The Brodie 1 Mine is documented to have human and wildlife visitation (NAMLRD 1991). No temporary or permanent structures for human habitation or livestock handling are on or within 0.25 mile of the site. Eight residential structures are located within 1 mile of the site ([Figure 4](#)). The flatter terrain upslope and downslope of the site provides potential locations for the siting of more houses, hogans, corrals, or stock-loading ramps. The likely future land use at the site is Kee'da'whíí tééh - full-time residential because the area is easily accessible and relatively flat ([Figure 9](#)). Land uses are further described in the “Navajo Nation-Wide Abandoned Uranium Mines Risk Assessment Conceptual Site Model and Methodology” (Risk Assessment CSM) (Tetra Tech, Forthcoming[b]).

The closest population center to the site is Red Mesa, Arizona ([Figure 1](#)). The Red Mesa community and rural residences in the Tse Tah region could be affected by the trucking of waste and imported construction materials that may be necessary depending on the selected remedy. Potential effects include the passage of trucks, road degradation, dust, and noise.

2.1.7 Sensitive Ecosystems and Habitat

The Brodie 1 Mine is within an Area 3 wildlife sensitive area as identified by the Navajo Nation Department of Fish and Wildlife (2008) and classified as having low, fragmented, or unknown concentrations of species of concern. Species in this area may be locally abundant on “islands” of habitat, but the islands are few and far between. Small-scale development to serve the needs of individuals, such as home sites and utilities, can proceed in an Area 3 wildlife without concern for significant impacts to biological resources.

Most of the habitat at the site is relatively flat, and the primary impacted environmental medium is soil. A large ephemeral drainage runs directly through the survey area boundary and drains into the Tse Tah West Wash, which flows north ([Figure 3](#)). No wetlands are located within the

drainage. Riparian/wetland habitat is particularly important for ecological health in arid ecosystems such as that in the Tse Tah Wash watershed in which the site is located.

The area occupied by the waste piles at the site is disturbed with little vegetation. Vegetated areas near the site are expected to provide better habitat for terrestrial receptors because plants serve as a food source and provide areas of refuge.

Based on a regional biological survey, potentially threatened and endangered species were not observed within the Tse Tah region. However, foraging habitat is present for burrowing owl (*athene cunicularia*), golden eagle (*Aquila chrysaetos*), ferruginous hawk (*Buteo regalis*), peregrine falcon (*Falco peregrinus*), and mountain plover (*Charadrius montanus*). Suitable denning habitat and marginal prey base also exists for kit fox (*Vulpes macrotis arsipus*) (Jacobs Engineering Group, Inc. 2019).

Although Mexican spotted owl (*Strix occidentalis lucida*) surveys were not performed within the Tse Tah Wash watershed, the site and surrounding area do not provide suitable Mexican spotted owl habitat.

2.1.8 Meteorology and Climate

The broad valleys of the Tse Tah region are classified as having a mid-latitude steppe, dry semiarid climate (Neptune and TSG 2018). Average high temperatures at the Teec Nos Pos weather station (028468) ranged from 41.5 degrees Fahrenheit in January to 93.1 degrees Fahrenheit in July for the period of record (June 1962 to June 2016) (Western Regional Climate Center 2021). The prevailing wind direction is from the west throughout the year (based on daily data from 2010 to 2016 collected at Farmington Four Corners Regional Airport, Farmington, NM). Days are typically clear or partly cloudy with monsoonal precipitation patterns in the summer and 5.4 inches average annual snowfall in the winter. Average monthly precipitation ranges from 0.26 inches in June to 1.16 inches in August. The average annual precipitation is 8.09 inches. The summer monsoon rains can occur from mid-July until the end of August, limiting access to drainages and use of access roads. [Figure 10](#) shows the monthly average temperature, precipitation, and evapotranspiration representative of the Tse Tah Region.

2.2 PREVIOUS RECLAMATION AND REMOVAL ACTIONS

During the NA-0507 Carrizo 1 reclamation project completed by NAMLRD in 1999 at the Brodie 1 Mine, one mine portal was closed and stabilized, a portion of a waste pile was placed in a burial cell, and a diversion berm was constructed above the portal (Weston Solutions, Inc. [Weston] 2016; Tetra Tech 2019). A short section of the access road used by NAMLRD closest to the site boundary was eliminated by scarification to reduce future access. The remainder of the access road leading north toward residential structures was left unreclaimed. [Appendix A](#) provides photographs of reclaimed features. [Table 1](#) summarizes the descriptions and dimensions for each mine and reclamation feature, and [Figure 5](#) presents the reclamation features.

NAMLRD completed the following reclamation activities at the site:

- Portal 41 (9 feet wide by 7 feet high) was stabilized and closed with a 76-square-foot cement block bulkhead using 5 cubic yards of concrete-filled reinforced masonry.

Exterior backfilling using mine waste from Waste Pile 41 was planned but not completed because the earth-moving equipment could not access the area. A dry rock wall was manually constructed outside the bulkhead.

- Waste Pile 41 was excavated removing 250 cubic yards of mine waste that was transported a short distance, and buried within Burial Cell 41.
- Burial Cell 41 was excavated to a depth of approximately 4 feet before mine waste was placed within the cell. Approximately 210 cubic yards of excavated material was stockpiled north of the excavation. After the mine waste was placed within the burial cell, Burial Cell 41 was covered to a minimum depth of 1.5 feet with 150 cubic yards of stockpiled material.
- Berm 41 was constructed along approximately 60 feet of the upper area of the site, and upslope of Portal 41 to divert surface water. Approximately 60 cubic yards of stockpiled material from the excavated burial cell was used to construct the berm.

During the 2018 RSE investigation, inspection of the closed portal did not reveal visible evidence of failure of the NAMLRD reclamation ([Appendix A](#)). However, a small, incised tributary to the Tse Tah West Wash is eroding headward toward Burial Cell 41. As of 2018, the headward erosion had not yet reached Burial Cell 41.

2.3 PREVIOUS SITE INVESTIGATIONS

Before the 2018 RSE field investigations by Tetra Tech (2019), no soil or groundwater samples had been collected from the Brodie 1 Mine. The previous environmental investigations for the site include:

- NAMLRD (1991) inventory assessment conducted from 1989 to 1992 to identify the location of and historical information for the site.
- U.S. Department of Energy aerial gamma radiation surveys to identify areas at the site with elevated radiation levels (Bechtel Nevada 2001).
- Weston (2010) preliminary assessment report to verify the location of and waste types present at the site.
- USEPA (2015) airborne spectral photometric environmental collection technology survey in 2014 and 2015 to identify areas at the site with elevated radiation levels.
- Weston (2016) mine categorization and assessment protocol investigation that included site mapping, verification of waste pile extents, and gamma radiation surveys.
- Tetra Tech (2019) RSE field investigation in 2018 that included gamma radiation surveys, X-ray fluorescence (XRF) field measurements, collection and analysis of surface and subsurface soil samples, and a cultural resource evaluation. The RSE also included an investigation of the mine, access roads, and the unnamed drainage leading from the site. A culturally sensitive area was identified in the northeast corner of the site survey area where a non-intrusive XRF field survey and gamma radiation survey was conducted with cultural monitors present.

More detailed descriptions of the previous investigations, including summaries of the analytical data, are included in the “Northern Agency Tronox Mines RSE Report” (Tetra Tech 2019).

2.4 SOURCE, NATURE, AND EXTENT OF CONTAMINATION

The source, nature, and extent of waste materials were characterized during the RSE investigations. The following subsections present the results of the background investigation and identification of contaminants of potential concern (COPC) and contaminants of potential ecological concern (COPEC); sources and nature of contamination; extent of contamination; and identification of exposure units.

2.4.1 Contaminants of Potential Concern, Contaminants of Potential Ecological Concern, and Background Threshold Values

Tetra Tech (Forthcoming[b]) identifies Ra-226, arsenic, selenium, uranium, and vanadium as COPCs and COPECs for the Northern AUM region. Human health and ecological RBSLs were developed for various land uses (see [Section 2.1.6](#)) in the Navajo Nation using agreed-upon exposure parameters and published ecological risk-based lowest observed effects concentrations (LOEC). Geology-specific background concentrations for Ra-226 and metal COPCs and COPECs (arsenic, selenium, uranium, and vanadium) representing soils in the Tse Tah region were evaluated at regional scales for the two geological units present at the Brodie 1 Mine (San Rafael Group and lower Morrison Formation) and the geological unit underlying the Tse Tah West Wash (Quaternary alluvium). Provisional BTVs were also calculated for each regional geologic unit (Tetra Tech 2021). For purposes of the AAM, the BTV is based on the 95 percent upper tolerance limit with 95 percent coverage (UTL-95-95).

[Table 2](#) presents a screening of the maximum detected site concentrations for each geological formation for the Brodie 1 Mine and Tse Tah West Wash with the RBSLs and the regional geology-specific 95 percent upper confidence limit (UCL95) concentrations and provisional BTVs. In San Rafael Group, maximum concentrations of Ra-226, arsenic, uranium, and vanadium exceed human health RBSLs, at least one ecological RBSL, and provisional BTVs, and maximum concentrations of selenium exceed at least one ecological RBSL and the provisional BTV. In the lower Morrison Formation, maximum concentrations of arsenic and uranium exceed the human health RBSL and ecological RBSL but not the provisional BTV. Data are not available within the technologically enhanced naturally occurring radioactive material (TENORM) area of lower Morrison Formation for Ra-226 or selenium, and vanadium was not detected in the two XRF in situ measurements. In the Tse Tah West Wash within Quaternary alluvium, the maximum concentration of Ra-226 exceeded the human health RBSL but did not exceed any ecological RBSL or the provisional BTV. None of the metals exceeded either the human health or ecological RBSLs or the provisional BTVs. Risk to human and ecological receptors from these COPCs is evaluated in [Section 2.5](#).

2.4.2 Source and Nature of Contamination

Data characterizing the source and nature of contamination is used to define site characteristics, identify migration pathways, and support the risk assessment at a site. Data on waste physical and chemical characteristics are used during the selection and design of removal action alternatives.

The primary source of contamination at the Brodie 1 Mine is the bedrock of the Salt Wash Member of the Morrison Formation of the Morrison Formation. The secondary sources of contamination include waste rock piles, burial cells, mining-exposed naturally occurring radioactive material (NORM) at highwalls and roads, and remobilization of contaminated fluvial deposits in the Tse Tah West Wash. The conceptual site model [CSM] wire diagram presented in [Figure 11](#) shows the primary and secondary sources of contamination, primary and secondary release mechanisms, and exposure media, as well as potential human health and ecological receptors and exposure pathways (discussed in [Section 2.5](#)).

No geotechnical analysis of soils at Brodie 1 Mine has been completed. The sandy waste rock was produced from the driving of tunnels through sandstone and mudstone to reach and extract the ore bodies. Short adits and small stopes were used to extract the ore from the mine, and no air shafts are known at the site. Waste remains on the site below the portal, in the two unreclaimed commingled waste piles, and within the burial cell. Areas with gamma levels above background remain outside of the burial cell and unreclaimed waste pile. Offsite migration is also possible via the surface water pathway, which could convey waste downgradient of the site to the wash below. However, this potential offsite migration pathway could not be confirmed based on the gamma radiation survey and sediment sampling results.

The primary contaminant transport pathways are erosion of waste or contaminated soil by surface water and redeposition downstream ([Figure 12](#)). Wind erosion of waste may also move contamination from the surface of the mine waste to adjacent areas. Fluvial and aeolian waste deposits may be remobilized and transported off site. Radon gas emanation and the leaching and dissolution of metals and radionuclides for waste may also occur.

2.4.3 Extent of Contamination

Data characterizing the extent of contamination (collected through the measurement of radiation intensity through gamma scan surveys and total metals and radionuclides concentrations during the RSE) is used to support the risk assessment and removal decisions.

Gamma Radiation in Surface Soils

The areas below the Brodie 1 Mine portal where waste rock is present exhibit gamma activity above background levels. [Figure 13](#) presents the gamma survey data at the site compared to the UCL95 of the background dataset, BTV, and multiples of the UCL95. The elevated gamma levels do not extend to the Tse Tah West Wash. Elevated gamma levels were recorded at Burial Cell 41, reclaimed Waste Pile 41, and Waste Pile M1. There are naturally exposed mineralized portions of the lower Morrison Formation on the cliff edge north of the portal.

Metals and Radionuclides in Surface Soils

Five primary sampling techniques were used to evaluate metals and radionuclide concentrations and to assess risk to human health and ecological receptors at the Brodie 1 Mine:

1. In situ XRF measurements (for a subset of metals)
2. XRF confirmation soil sampling

3. Surface soil sampling
4. Subsurface soil sampling
5. Sediment sampling

Gamma scan data, due to greater coverage and density, has been used as a surrogate to evaluate the extent of Ra-226 contamination. A Tronox correlation between gamma readings in counts per minute (cpm) and Ra-226 in picocuries per gram (pCi/g) has been developed to utilize existing gamma count readings to estimate the extent of Ra-226 contamination. Figure 14 presents the interpolated surface of estimated Ra-226 with laboratory results for Ra-226 overlain; the confirmation soil sampling results for Ra-226 correlated well with concentrations estimated from gamma readings. RSE data from correlation plots distributed in the Tse Tah region were included in the evaluation, resulting in the following gamma-radium correlation equation (Tetra Tech 2019):

$$\text{Equation 1: Estimated Ra-226 (pCi/g)} = (0.001307 \times [\text{gamma (cpm)}]) - 10.691$$

The Tse Tah correlation was adjusted using empirical observations, and Equation 2 was applied to adjust the Ra-226 concentrations, resulting in Equation 3, which was used to predict Ra-226 concentrations at the site (Tetra Tech, Forthcoming[a]).

$$\text{Equation 2: Adjusted Estimated Ra-226 (pCi/g)} = 0.3732 \times [\text{Ra-226}_{(\text{predicted from Equation 1})}] + 0.4068$$

$$\text{Equation 3: Estimated Ra-226 (pCi/g)} = [(0.001307 \times [\text{gamma (cpm)}]) - 10.691] * 0.3732 + 0.4068$$

Figure 14 presents the estimated Ra-226 surface soil concentrations compared to the UCL95 of the background dataset, BTV, and multiples of the UCL95. Gamma survey data, converted to estimated radium-226, were interpolated using ESRI's Geostatistical Wizard using the following model: Simple Kriging using a normal score transformation and the semivariogram variable and a smooth search neighborhood with a smoothing factor of 0.2. At the site, the elevated Ra-226 concentrations are mostly present within the extent of the waste rock piles, burial cells, mineralized rock outcrops, roads, and fluvial deposits containing mine waste.

Areas with elevated metals concentrations are generally collocated with areas where Ra-226 concentrations are highest. In an evaluation of Tronox AUM surface soil data within the Northern AUM region, arsenic, selenium, uranium, and vanadium occurred at elevated concentrations more frequently than other metals outside the areas where Ra-226 concentrations exceed background levels (Tetra Tech, Forthcoming[b]). Exceedances of metals within the TENORM extent (see below) outside the areas where estimated Ra-226 concentrations are predicted to be greater than the geology-specific BTVs are presented on Figure 15.

During the RSE, 309 soil and sediment samples across the Northern AUM region within AUM sites and downgradient drainages were analyzed for uranium series isotopes to determine equilibrium conditions of uranium decay series radionuclides measured at Tronox AUM sites. A range of equilibrium conditions were observed, and results from the analysis support the assumption of secular equilibrium between Ra-226 and its decay products (Tetra Tech 2019).

Sediment Sampling Results

The Tse Tah West Wash is located north of the Brodie 1 Mine. Sediment samples were collected and analyzed for metals and radionuclides, and none of the sample results for Ra-226 or metals exceeded the applicable provisional regional BTV ([Table 2](#)). Additionally, most of the gamma radiation measurements within the Tse Tah West Wash were in the range of background except for a portion of the wash northeast of the Brodie 1 Mine that drains a broad area of NORM comprising the lower Morrison Formation ([Figure 13](#)).

Mine Water

Discharge or retention of water at Portal 41 was not documented during the 1999 NAMLRD reclamation or during the 2018 RSE investigation.

TENORM and NORM Delineation

NORM that has been concentrated and displaced because of human activities through a process of concentrating the radiological, physical, and chemical properties of the radioactive material by processing or disturbance is considered TENORM. At the Brodie 1 Mine, TENORM areas include soil disturbed within and around the burial cell, reclaimed and unreclaimed waste piles, reclaimed portal, and berm. In addition, areas downgradient of the portal, waste pile, and burial cell area, including a rockfall area near the reclaimed waste pile, with elevated Ra-226 concentrations are considered TENORM. The area north of Burial Cell 41 is mapped as TENORM because of the disturbed land observed, and the drainage path leaving the site is also mapped as TENORM because of the elevated Ra-226 concentrations and association with onsite mining features. [Table 4](#) presents the summary statistics for Ra-226, arsenic, selenium, uranium, and vanadium for surface soil (0 to 12 inches below ground surface [bgs]) in the TENORM area. [Figure 14](#) presents the extent of NORM and TENORM at the site, which covers 1.3 acres (about 56,700 square feet), and [Appendix B](#) presents the lines-of-evidence for determining the TENORM boundary.

Areas that lie within the host unit and are undisturbed by mining activity or impacted by natural waste transport processes are considered NORM. At the Brodie 1 Mine, NORM areas include upslope land, bedrock outcrops outside the area of mining activity, and inclusions of bedrock outcrops within an area otherwise disturbed by mining activity, as well as areas impacted by transport of material from undisturbed areas. The site sits on two different geologies: the northwest portion of the site is within San Rafael Group whereas the southeastern portion of the site lies within the lower Morrison Formation. As a result, most of the southeast portion of the site, excluding the berm, is mapped as NORM because this area is undisturbed, has low levels of Ra-226 concentrations, and lies in the lower Morrison Formation host rock unit. Additionally, the areas within San Rafael Group where no evidence of mining disturbance was found and the interpolated Ra-226 was at or below background were not included in the TENORM boundary.

2.4.4 Exposure Units

Exposure units (EU) for use in the risk assessment and future removal actions within the TENORM area were developed by identifying areas with a common land use and geology to match areas with distinct cleanup goals. EUs do not have size restrictions for Navajo Nation

AUMs. [Figure 16](#) presents EUs identified at the Brodie 1 Mine; land uses are described in [Section 2.1.6](#). Data are available for surface soil (0 to 12 inches bgs) ([Table 3](#)). In addition, the Tse Tah West Wash was evaluated using sediment samples from 0 to 6 inches bgs. Sediment samples collected during the RSE are considered equivalent to soil samples for the purposes of the risk assessments because of the dry conditions within drainages for most of the year. Four EUs were identified at the Brodie 1 Mine:

- EU 1 – Kee'da'whíí tééh (Full-Time Navajo Resident) in San Rafael Group
- EU 2 – Kee'da'whíí tééh (Full-Time Navajo Resident) in lower Morrison Formation
- EU 3 – Chíí dah wiíh łeezh (Washes and Drainages) in Quaternary alluvium
- EU 4 – Kee'da'whíí tééh (Full-Time Navajo Resident) Burial Cell 41 in San Rafael Group (subsurface soil only)

[Table 3](#) presents the analytical sample data available in each EU.

2.5 RISK ASSESSMENT

Risk assessments were completed to evaluate the potential risk posed to human and ecological health by Tronox mine-related contamination. The results of the HHRA and ERA are used to assist in cleanup decisions at the Brodie 1 Mine through the EE/CA process. The compiled RSE investigation data were reviewed to ensure the appropriate data were used for the evaluation of each EU. Data compilation and management tasks included the selection of useable data, establishment of exposure areas, evaluation of sample depth intervals and selection of depth intervals, and calculation of the exposure point concentration (EPC) and other statistical values. [Appendix C](#) presents the data included in the HHRA and ERA. The compiled EPCs for each EU for each relevant soil depth interval are provided in [Table 5](#).

2.5.1 Purpose

The purpose of the risk assessment is to evaluate current and future human health risk under Navajo-specific RME scenarios and ecological risk based on the known ecosystems for the region. The methodology used in the HHRA and ERA is provided in the Risk Assessment CSM (Tetra Tech, Forthcoming[b]). The risk assessment identifies human health COCs and COECs in each EU. In addition, the results of the risk assessment are used to determine RAGs and the extent of removal to meet the goals.

2.5.2 Human Health Risk Assessment

An HHRA is the process for evaluating how humans will be impacted as a result of exposure to one or more environmental stressors, such as chemicals or radiation. The objective of the HHRA is to evaluate whether COPCs detected at each EU pose unacceptable cancer risks or noncancer hazards to potential current and future human receptors under conditions at the time of the EE/CA (unremediated conditions) (USEPA 1989b, 1993). Consistent with Superfund methodology (USEPA 1989b), Tetra Tech assumes that the risks and hazards related to remedial work at the sites for AUM workers will be managed within acceptable levels using engineering controls and personal protective equipment. Therefore, potential exposures to AUM workers are

not evaluated as part of the HHRA. The HHRA is intended to provide input for risk management decision-making for a site.

The HHRA includes the following components: data evaluation and selection of COPCs, exposure assessment, toxicity assessment, and risk characterization. The methodology used in the HHRA is provided in the Risk Assessment CSM (Tetra Tech, Forthcoming[b]).

For the Brodie 1 Mine, two Navajo-specific receptors were identified as shown in the CSM (Figure 11). A graphic depiction of other potential Diné Lifeways exposure pathways is also provided on Figure 17. The human health CSM identifies potentially complete exposure pathways by which receptors could come in contact with site-related contaminants. The CSM provides a description of the various RME scenarios or relevant activities that could occur at the site and the pathways in which a contaminant may be contacted, internalized, or ingested by an individual at the site. The CSM is used throughout the site investigation and removal processes to (1) provide a framework for addressing potential risks, (2) evaluate the need for additional data acquisition activities, and (3) evaluate health risks and the need for corrective measures. The following table provides the RME scenarios evaluated at the Brodie 1 Mine and the complete exposure pathways included in each scenario.

Exposure Media	Exposure Pathways	Human Health Exposure Scenarios	
		Kee'da'whíí tééh (Full-Time Navajo Resident)	Chíí dah wíih íeezh (Washes and Drainages)
Gamma Radiation	External Exposure (radioisotopes only)	●	●
Soil and Sediment	Incidental Ingestion Dermal (Metals only) Inhalation	●	●
Homegrown Produce	Ingestion	●	●
Gathered Plants	Ingestion Dermal (Metals only) Inhalation	●	●
Animal Products (raised and hunted)	Ingestion	●	●

Notes:

All receptors are assumed to obtain drinking water from offsite supplied sources and do not consume surface or groundwater at abandoned uranium mines.

● Potentially complete exposure route will be evaluated for the receptor

In the context of the regulatory risk assessment process, potential effects of contaminants are separated into two categories: cancer and noncancer effects. For carcinogens, such as radionuclides and arsenic, USEPA assumes that no dose is low enough to not cause a health effect and that some increased risk is at every dose level. Noncancer COPCs, such as uranium, are toxic above a threshold dose. Potential health risks for radionuclide COPCs are evaluated only for cancer risks while metals COPCs are evaluated for both cancer risks and noncancer hazards as appropriate. COPCs are limited to those determined to be regional COPCs or COPECs, which are Ra-226, arsenic, selenium, uranium, and vanadium (Tetra Tech, Forthcoming[b]).

Potential human exposure at the Brodie 1 Mine is limited to radionuclides and metals in surface soil (0 to 12 inches bgs). The depth of the sample is based on its bottom depth. Additionally, potential exposure to sediment (0 to 6 inches bgs) within the Tse Tah West Wash is also evaluated as EU 3. Water exposure is not evaluated at the site because the RSE focused on the characterization of soil and sediment only.

RBSLs were developed for the Navajo-specific RME scenarios above using a target cancer risk of three in ten thousand (3E-04) and a target hazard quotient (HQ) of 1. These values were selected based on consultation with the Navajo Nation Environmental Protection Agency (NNEPA). The process and inputs for the calculation of the RBSLs for each Navajo-specific scenario is provided in the Risk Assessment CSM (Tetra Tech, Forthcoming[b]). Human health RBSLs were derived for applicable receptors and radionuclide and metals COCs using all potentially complete soil-related exposure pathways. For Ra-226, the human health RBSL is the carcinogenic-based screening level assuming secular equilibrium of Ra-226 and its decay products.

In the HHRA, EU-specific EPCs were compared to RBSLs to determine whether site concentrations pose unacceptable risks or hazards. For analytes with EPCs exceeding the RBSL, EU-specific EPCs for each COPC were also compared with regional geological formation-specific BTVs developed for use in the EE/CA. COCs were identified as those COPCs with a total cancer risk greater than 3E-04 (radionuclides and metals) or a HQ greater than 1 (metals only) and EPCs greater than the geologic formation-specific BTVs.

Table 6 presents the RBSLs calculated for cancer risk and noncancer hazard (child and adult). The cancer risk (age-adjusted adult and child) and non-cancer hazards for child and adult receptors for each EU and soil interval are provided in Table 7. Table 8 compares the calculated EPCs for the COCs to the calculated RBSL and BTV to identify the COCs that should be considered in the removal action.

The following COCs were recommended for removal action for each EU:

Exposure Unit ¹	Matrix (Depth Interval, inches below ground surface)	Contaminant of Concern		
		Radium-226	Uranium	Vanadium
1	Surface Soil (0-12)	X	X	X
2	Surface Soil (0-12)	-- ²	--	-- ²
3	Sediment (0-6)	--	--	--
4	Subsurface Soil (12-72)	-- ²	-- ²	-- ²

Notes:

¹ The exposure units (EU) include:

- EU 1 - Kee'da'whíí tééh (Full-Time Navajo Resident) within the San Rafael Group
- EU 2 - Kee'da'whíí tééh (Full-Time Navajo Resident) within the lower Morrison Formation
- EU 3 - Chíí dah wiíh íeezh (Washes and Drainages) within Quaternary alluvium
- EU 4 - Kee'da'whíí tééh (Full-Time Navajo Resident) Burial Cell 41 in the San Rafael Group

² No analytical data are available.

-- Not recommended for removal action for the EU based on human health risk assessment results.
(Note: Multiple lines of evidence are used in determining whether an EU will have a removal action. Identification of the contaminants of concern is one of these lines of evidence. Other lines of evidence include identification of contaminants of ecological concern, known contamination [such as a burial cell], or elevated gamma radiation readings.)

X Human health contaminant of concern recommended for removal action for the EU.

COCs for all EUs were identified based on available laboratory and XRF sample data; however, the determination of the removal action extent takes into account other lines of evidence. Although no COCs were identified for removal in EU 2, EU 3, and EU 4, Ra-226 is a known contaminant at AUMs. Therefore, gamma survey data converted to estimated Ra-226 concentrations will be used as a line of evidence to develop the removal action extent for each EU as discussed in [Section 2.6](#).

2.5.3 Ecological Risk Assessment

An ERA is the process for evaluating how likely the environment will be impacted as a result of exposure to one or more environmental stressors, such as chemicals. The objective of the ERA is to evaluate whether ecological receptors may be adversely affected by exposure to site-related contaminants. The ERA is intended to provide input for risk management decision-making at each EE/CA group while maintaining a conservative approach protective of ecological populations and communities (USEPA 1992, 1997, 1998, 2001).

The ERA includes the following components: problem formulation, analysis of exposure and effects, and risk characterization. Ecological RAGs were identified based on the results of the risk characterization.

As discussed in [Section 2.4.1](#), COPECs are limited to those determined to be COPCs or COPECs in the Northern AUM region. The following representative feeding guilds are evaluated in the ERA, which are exposed to soil in the following depth intervals:

- Plants (0 to 72 inches bgs)
- Soil invertebrates (0 to 12 inches bgs)
- Avian herbivores (0 to 12 inches bgs)
- Avian ground insectivores (0 to 12 inches bgs)
- Avian carnivores (0 to 12 inches bgs)
- Mammalian herbivores (0 to 72 inches bgs)
- Mammalian ground insectivores (0 to 72 inches bgs)
- Mammalian carnivores (0 to 72 inches bgs)

Ecological receptors were evaluated using available data. Surface soil (0 to 12 inches bgs) data were used to evaluate exposure to ecological receptors in EUs 1 and 2 whereas surface sediment data (0 to 6 inches bgs) were used to evaluate exposure in EU 3; no soil data were available in EU 3.

As indicated in the CSM ([Figure 11](#)), the potentially complete ecological exposure pathways evaluated in the ERA were:

- Potential exposure of soil invertebrates and terrestrial plants to site-related contaminants present in soil and sediment via direct contact.

- Potential exposure of wildlife (birds and mammals) to site-related contaminants present in soil and sediment through the ingestion of site-related contaminants in soil, forage, and prey items.

Ecological RBSLs were selected for each feeding guild from the Los Alamos National Laboratory ECORISK database. RBSLs are based on LOECs, the lowest concentration where an effect has been observed in chronic ecotoxicity studies (Newport News Nuclear BWXT-Los Alamos, LLC. 2020).

In the ERA, EU-specific EPCs were compared to ecological RBSLs to calculate a HQ. HQs greater than 1 indicate a potential for ecological risk because the LOEC is based on an observed adverse effect concentration. For analytes with HQs exceeding 1, EU-specific EPCs for each COPEC were also compared with regional geological formation-specific BTVs developed for use in the EE/CA.

The HQs for each EU and soil interval for each representative feeding guild are provided in [Table 9](#). [Table 10](#) compares the calculated EPCs for the COPECs with a maximum HQ exceeding 1 to the RBSL and BTV to identify the COPECs that should be considered in the removal action.

The following COECs were recommended for removal action for each EU:

Exposure Unit	Matrix (Depth Interval, inches below ground surface)	Contaminant of Ecological Concern	
		Radium-226	Vanadium
1	Surface Soil (0-12)	--	X
2	Surface Soil (0-12)	-- ²	--
3	Sediment (0-6)	--	--
4	Subsurface Soil (12-72)	-- ²	-- ²

Notes:

¹ The exposure units (EU) include:

EU 1 - Kee'da'whíí tééh (Full-Time Navajo Resident) within the San Rafael Group

EU 2 - Kee'da'whíí tééh (Full-Time Navajo Resident) within the lower Morrison Formation

EU 3 - Chíí dah wííh íeezh (Washes and Drainages) within Quaternary alluvium

EU 4 - Kee'da'whíí tééh (Full-Time Navajo Resident) Burial Cell 41 in the San Rafael Group

² No analytical data were available.

-- Not recommended for removal action for the EU based on ecological risk assessment results.
(Note: Multiple lines of evidence are used in determining whether an EU will have a removal action. Identification of the contaminants of ecological concern is one of these lines of evidence. Other lines of evidence include identification of the contaminants of concern, known contamination [such as a burial cell], or elevated gamma radiation readings.)

X Contaminant of ecological concern recommended for removal action for the EU.

COECs for all EUs were identified based on available laboratory and XRF sample data; however, the determination of the removal action extent takes into account other lines of evidence. Although no COECs were identified in EU 2 and EU 3, Ra-226 is a known contaminant in AUMs. Therefore, gamma survey data converted to estimated Ra-226 concentrations will be used as a line of evidence to develop the removal action extent for each EU as discussed in [Section 2.6](#).

2.5.4 Risk Assessment Results Summary and Identification of Removal Action Goals

Human health and ecological RAGs were derived for each applicable receptor, EU, and COC or COEC recommended for removal action. [Table 11](#) summarizes the surface and subsurface soil EPCs, the human health and ecological RBSLs, the provisional regional BTV for each EU, and the RAG. The RAG is the lesser of the human health and the ecological RBSLs unless either RBSL is less than the BTV. If the BTV is higher than either RBSL, then the RAG is to address material that is distinguishable from background. For purposes of this AAM, the BTV is used to represent background for delineating contaminated areas. The following table provides the selected RAG for each COC and COEC for each EU.

COC or COEC	Units	Human Health RBSL ¹	Ecological RBSL ²	BTV ³	RAG ⁴
EU 1 - Surface Soil (0-12 inches below ground surface)⁵					
Radium-226 ⁶	pCi/g	0.11	--	1.4	1.4
Uranium	mg/kg	0.92	--	0.90	0.92
Vanadium	mg/kg	27	9.5	9.7	9.7

Notes:

- ¹ The human health RBSL is based on the full-time resident. For metals with both carcinogenic and noncarcinogenic effects, the human health RBSL is the lesser (more conservative) of the carcinogenic- and noncarcinogenic-based screening levels presented in [Table 6](#).
 - ² The ecological RBSL is based on the minimum LOEC for all feeding guilds evaluated for the depth interval.
 - ³ The BTV is for the identified geologic unit for each EU.
 - ⁴ The RAG is the lesser of the human health RBSL and the ecological RBSL unless either RBSL is less than the BTV. If the BTV is higher than either RBSL, then the RAG is to address material that is distinguishable from background. For purposes of this AAM, the BTV is used to represent background for delineating contaminated areas.
 - ⁵ Human health COCs are identified based on exposure to surface soil or if subsurface soil could be exposed in the future and become surface soil; ecological COECs are identified based on exposure to surface soil.
 - ⁶ Secular equilibrium is assumed for radium-226 for calculation of human health risks.
 - Not a COC or COEC
- AAM Alternatives analysis memorandum
 BTV Background threshold level
 COC Contaminant of concern
 COEC Contaminant of ecological concern
 EU Exposure unit
 LOEC Lowest observed effect concentration
 mg/kg Milligram per kilogram
 pCi/g Picocurie per gram
 RAG Removal action goal
 RBSL Risk-based screening level

COCs and COECs were identified based on available laboratory and XRF sample data. The HHRA and ERA results indicate that removal action is recommended for surface soils in EU 1. No samples were collected within EU 4 (Burial Cell 41); therefore, not enough data are available to make human health and ecological risk recommendations. However, cleanup within the burial cell is recommended because the burial cell is known to contain waste rock with elevated gamma levels as previously identified by NAML RD (Weston 2016). Furthermore, any area where waste is left in place must satisfy long-term effectiveness requirements and the burial cell cover likely does not meet performance standards.



One sample within the 6 to 12 inches bgs depth interval was the only sampled collected deeper than 6 inches at the Brodie 1 Mine. Therefore, a large amount of uncertainty is associated with subsurface risks and hazards, as well as related conclusions regarding the need for and extent of any subsurface soil cleanup.

The determination of the removal action extent, as described in [Section 2.6](#), takes into account other lines of evidence. Therefore, although no COCs or COECs were identified at EU 2, EU 3, and EU 4, Ra-226 is a known contaminant in AUMs and gamma survey data converted to estimated Ra-226 concentrations will be used as a line of evidence to develop the removal action extent for each EU. RAGs for Ra-226 in EU 2, EU 3, and EU 4 based on the proposed land use and underlying geological unit are presented below and used in the derivation of the Ra-226 removal action extent:

- EU 2 - Kee'da'whíí tééh (Full-Time Navajo Resident) within lower Morrison Formation: 6.3 pCi/g
- EU 3 - Chíí dah wiíh íeezh (Washes and Drainages) within Quaternary alluvium: 2.3 pCi/g.
- EU 4 - Kee'da'whíí tééh (Full-Time Navajo Resident) Burial Cell 41 within San Rafael Group: 1.4 pCi/g.

2.6 REMOVAL ACTION EXTENT

Multiple lines of evidence were used to develop the removal action extent at the Brodie 1 Mine and Tse Tah West Wash, including the extent of Ra-226 in surface soil and sediment, extent of contamination of other COCs and COPECs not colocated with Ra-226, surface and subsurface waste areas, transport pathways, disturbed mineralized areas, accessibility considerations, and risk management considerations.

2.6.1 Radium-226 Removal Action Extent

The gamma survey data at the Brodie 1 Mine and Tse Tah West Wash were evaluated and converted to estimated Ra-226 concentrations to determine the Ra-226 removal action extent. A *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM)-based (USEPA 2020) approach using area averaging was employed that evaluated estimated Ra-226 concentrations against the EU-specific Ra-226 screening level within 2,000-square meter survey units and the BTV. For purposes of the AAM, the BTV is based on the 95 percent upper tolerance limit with UTL-95-95. A hot spot evaluation was also conducted to identify 100-square meter areas with average concentrations exceeding twice the RAG; these areas were added to the preliminary removal action footprint. Contiguous 100-square meter areas with average concentrations below the RAG were removed from the survey unit designated for removal action.

Once this evaluation was conducted for each EU, the resulting Ra-226 removal action extents were combined to determine the preliminary removal action extent for Ra-226 at the Brodie 1 Mine and Tse Tah West Wash.

2.6.2 Removal Action Extents – Other Considerations

Additional lines of evidence were considered when modifying the preliminary removal action extent, specifically:

- **Extent of contamination of other COCs or COECs not colocated with Ra-226:** Areas outside the Ra-226 removal action extent with elevated concentrations of other COCs or COECs were added iteratively to the preliminary removal action extent until the resulting EPC within each EU was less than the RAG.
- **Surface and subsurface waste areas:** Waste rock piles and subsurface reclamation mine features such as burial cells were added to the preliminary removal action extent.
- **Transport pathways:** Mine features and areas (for example, waste rock on benches and rimstrips) with potential for future transport of waste material downgradient to other geologic units with lower RAGs were added to the removal area.

The following additional lines of evidence were considered but not applicable to the Brodie 1 Mine:

- **Accessibility considerations:** Inaccessible areas.
- **Risk management considerations:** Areas that if disturbed, may result in destabilization of slopes (for example, by removing vegetation) and transport of material downgradient.

Figure 18 presents the final proposed removal action extent and areas targeted for surficial restoration at the Brodie 1 Mine; no removal action is recommended for the Tse Tah West Wash. The total calculated surface area and volumes within the proposed removal action extent broken down by the waste pile, burial cell, and other contaminated surface areas are:

- Waste pile: 2,331 square feet; 345 cubic yards
- Burial cell: 1,245 square feet; 277 cubic yards
- Other surficial contamination: 5,676 square feet; 210 cubic yards

3.0 NAHAT'A - IDENTIFICATION OF REMOVAL ACTION OBJECTIVES

3.1 REMOVAL ACTION OBJECTIVES

The first step in developing removal action alternatives is to establish RAOs. Under CERCLA, removal action alternatives may not require remediation of NORM or soil to concentrations below background levels. Taking current and potential future land use and Navajo cultural considerations into account, the RAOs are to:

- Prevent exposure to soil with contaminants that would pose an unacceptable risk to human health with residential use and traditional Diné lifeways outside of any potential capped area.
- Prevent exposure to soil with contaminants that would pose an unacceptable risk to human health with traditional Diné lifeways on any potential capped area. This may include exposures that occur during activities such as livestock grazing, hunting, and plant gathering and use.
- Prevent exposure to soil with contaminants that would pose an unacceptable risk to plants, animals, and other ecological receptors.
- Prevent migration of contaminants to surface water or groundwater that pose an unacceptable risk to human health.
- Prevent offsite migration of contaminants above background concentrations and at concentrations that could pose a risk to human health or the environment.

USEPA has developed the “Navajo Nation Abandoned Uranium Mines Technology Evaluation and Alternative Development Technical Memorandum” (Technology Technical Memorandum) (Tetra Tech, Forthcoming[c]) that describes the general response actions that will satisfy the RAOs listed above. A summary of the technology evaluation and alternative development process addressed in the Technology Technical Memorandum is provided in [Section 4.1](#). [Section 4.2](#) describes the retained removal action alternatives for the Brodie 1 Mine, and [Section 4.3](#) presents a detailed analysis of the removal action alternatives with respect to the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) effectiveness, implementability, and cost criteria. Section 5.0 presents a comparative analysis of the removal action alternatives.

3.2 STATUTORY LIMITS ON REMOVAL ACTIONS

Pursuant to CERCLA Section (§) 104(c)(1), the normal statutory limits for CERCLA removal actions of \$2 million and 12 months do not apply since the selected action will be funded by a responsible party and not by Superfund.

3.3 REMOVAL SCOPE

The scope of the removal action will be to address all solid media contamination at the Brodie 1 Mine and to be the final action for solid media at the site. The removal action will also protect against potential future impacts to groundwater and surface water. Post-removal action site



controls will be part of the analysis for an alternative that does not include the complete removal of contaminants off site.

3.4 REMOVAL SCHEDULE

This AAM was prepared without a preferred removal action alternative to provide an opportunity for public input on the removal action alternatives development and evaluation process. Following public input, a final EE/CA will be prepared, including a recommended removal action alternative for public comment.

NCP requires a minimum public comment period of 30 days following release of the proposed final EE/CA by USEPA. USEPA will respond to significant comments received during the public comment period and publish an action memorandum following the response to comments. USEPA will provide public notification of the removal action schedule upon issuance of the action memorandum.

During the implementation of the selected removal action alternative(s), several factors may affect the removal action schedule, including removal action planning and design, cultural and biological clearances and mitigation, seasonal weather-related restrictions, and access for construction equipment. Depending on the removal action alternative(s) selected in the final EE/CA, design and implementation of the construction activities will likely require between 1 and 2 months, depending on schedule-limiting factors such as truck availability, monsoon rains, and snowfall. Inspections and maintenance of graded and revegetated site surfaces will be required at the mine site for at least the first 10 years after restoration. Inspections and maintenance of the burial cell cover or repository cap, if selected, will be conducted as specified in a site-specific long-term surveillance plan (10 *Code of Federal Regulations* [CFR] § 40.28) with inspection frequencies adjusted based on cover or cap stability and inspection findings.

4.0 NAHAT'A - IDENTIFICATION AND ANALYSIS OF REMOVAL ACTION ALTERNATIVES

[Section 4.1](#) summarizes the screening process for potential technologies and identifies the removal action alternatives that may be effective and implementable at the Brodie 1 Mine; [Section 4.2](#) provides a detailed description of the retained removal action alternatives; [Section 4.3](#) provides a detailed analysis of the removal action alternatives based on the NCP defined criteria of effectiveness, implementability, and cost.

4.1 DEVELOPMENT AND SCREENING OF ALTERNATIVES

This section identifies general response actions, identifies and screens technologies, develops and describes potential removal action alternatives, and identifies the applicable or relevant and appropriate requirements (ARAR).

4.1.1 Summary of Technology Identification and Screening

The removal action alternative development process involves identifying general response actions, technology types, and process options that may satisfy RAOs. General response actions, technologies, and process options considered for all AUMs on the Navajo Nation have been identified, described, and initially screened in the Technology Technical Memorandum (Tetra Tech, Forthcoming[c]) and are presented in [Table 12](#), along with any modifications necessary to address the Brodie 1 Mine site conditions and local requirements. The initial screening eliminates from further consideration infeasible technologies and process options and retains potentially feasible technologies and process options.

A technology or process option can be eliminated from further consideration if it does not meet the effectiveness threshold criteria (protectiveness and compliance with ARARs) or substantive implementability criteria (technical, administrative, availability, and local acceptance), the details of which are described in [Section 4.3](#). In addition, a technology or process option can be eliminated if its cost is substantially higher than other technologies or process options and at least one other technology or process option is retained that offers equal protectiveness.

Technologies or Process Options Screened from Consideration. The following process options identified in the Technology Technical Memorandum (Tetra Tech, Forthcoming[c]) were removed from consideration as infeasible during development of this AAM for the Brodie 1 Mine:

- **Excavation and Disposal at Uranium Mill Tailing Radiation Control Act (UMTRCA) Sites.** Several UMTRCA sites were assessed for the Brodie 1 Mine waste and considered to be infeasible because sites were either closed, had insufficient capacity to receive the waste, or had groundwater contamination issues that could prohibit disposal under the CERCLA Off-Site Rule.
- **Excavation and Disposal Back into the Mine Adit and Workings.** Although Brodie 1 Mine development information is limited, the extent of the workings is believed to be limited and that most of the waste volume is from rock dislodge from the cliff face for

portal access. Access to the mine workings is no longer possible because of portal closure.

- **Disposal at a Local Municipal Solid Waste Landfill.** No municipal solid waste landfills are located on the Navajo Nation, but several landfills are located nearby in Arizona and New Mexico. Local landfills were screened from consideration as disposal options because uranium mine waste is specifically exempted from the definition of solid waste in state regulations. Thus, the permits for local landfills do not allow for disposal of uranium mine waste.

Analysis of Whether Treatment to Reduce Toxicity or Volume Is Practicable. CERCLA and NCP express a preference for treatment of waste that significantly and permanently reduces the volume, toxicity, or mobility of contaminants, where such treatments are practicable. CERCLA § 121(b), 40 CFR § 300.430(a)(1)(iii), and “A Guide to Principal Threat and Low Level Threat Waste” (USEPA 1991) describe how to identify wastes that may be appropriate for treatment. Although the action at the Brodie 1 Mine site is a removal action, USEPA has nevertheless fully considered whether the site contained any principal threat waste, whether that waste could safely be contained using engineering controls, and whether any treatment options may be practicable for the waste at the site. As a result of its investigation and analysis, USEPA concluded that, while individual samples at the site contained higher levels of contaminants that might be considered principal threat waste, the waste at the site is extremely variable and heterogeneous in its radiological activity and found no areas of waste rock that were clearly distinguishable as principal threat waste. In addition, consistent with USEPA (1991) guidance, USEPA found that the wastes at the site can be safely and reliably contained by appropriate engineering controls. Potential treatment options were reviewed, and USEPA’s analysis of the reasons why no currently available treatment options are practicable is presented below:

- **Phytoremediation** is a treatment process that uses plants to absorb radionuclides and other contaminants. This and similar alternative treatment methods were considered but screened as infeasible for the site. Most contamination at the site is contained in a burial cell up to 6 feet below the surface and would not be easily accessed by plant roots. In addition, plants used in phytoremediation need to be harvested and disposed of as a radioactive waste and human or animal consumption of the plants would need to be prevented. Because of the limited depth of root penetration and harvested material handling requirements, phytoremediation is determined not to be practicable.
- **Soil washing** is a treatment process that involves washing the contaminated medium (with water) in a heap, vat, or agitated vessel to dissolve water-soluble contaminants. Soil washing requires that contaminants be readily soluble in water and sized sufficiently small so that dissolution can be achieved within a practical retention time. The most common form of mineralization is tyuyamunite— $\text{Ca}(\text{UO}_2)_2(\text{V}_2\text{O}_8) \cdot (5-8)\text{H}_2\text{O}$ —with other members of the carnotite group of minerals also present. Carnotite group minerals dissolve slowly in water, making soil washing likely ineffective for removal to remediation goals. Metals solubility depends on the valence state of the metal compounds in the waste rock and can range from highly soluble to insoluble. Because of the low concentrations of uranium in the waste rock and varying solubilities at different pH ranges for radionuclides and metals of concern, soil washing will likely not meet cleanup goals and is determined not to be practicable.

- **Acid extraction** is similar to soil washing except an acidic solution is applied to the waste rock or other contaminated media in a heap, vat, or agitated vessel instead of water. Depending on temperature, pressure, and acid concentration, varying quantities of metal constituents present in the contaminated medium would be solubilized. A broader range of contaminants are expected to be acid soluble at ambient conditions via acid extraction than via application of soil washing. Because of the low concentrations of uranium in the waste rock and varying solubilities at different pH ranges for radionuclides and metals of concern, acid extraction will likely not meet cleanup goals and is determined not to be practicable.
- **Ablation** is a treatment technology that can be applied to sandstone-hosted uranium mineralization, where the uranium minerals form a crust on the sand grains. The ablation process mixes water and waste rock into a slurry that is injected into impact tank modules. The opposing slurry streams impact one another and collisions between the sandstone particles and fragments within each stream result in a disassociation of fine-grained, intergranular, and mineralized material (uranium minerals) from coarser-grained sands. Ablation technology has potential with some small commercial systems in operations and with pilot-scale studies planned to test the feasibility of the technology for treating waste rock with low uranium concentrations. However, ablation technologies have not proven capable of removing low concentration uranium from waste similar to the waste rock at the site and are not of sufficient throughput to address a large volume of waste rock in a timely manner. Therefore, ablation is determined not to be practicable.
- **Milling** is a commercial process that removes uranium by a combination of several methods including pulverization and acid extraction. The concentration of uranium in the waste rock at the site is very low, so any processing would therefore yield only a minimal amount of uranium. Additionally, milling does not remove radium and the resulting mill waste is neither less toxic nor less mobile than the source material. Thus, milling is determined not to be practicable for the treatment of uranium mine waste. However, milling may be considered as a pretreatment step for recovering an economic quantity of uranium before disposal in a tailings disposal facility and is, therefore, retained as a disposal process option.

If the treatments discussed above or any other treatment methods are shown to be effective and practicable before the selection of a remedy, USEPA will amend this analysis and consider such treatment.

Retained technologies and process options are combined into a range of potential removal action alternatives in [Section 4.1.2](#).

4.1.2 Summary of Alternative Development

Excavation and disposal is the only technology identified as implementable and effective for the Brodie 1 Mine. Removal action alternatives for AUMs on the Navajo Nation were developed as described in the Technology Technical Memorandum (Tetra Tech, Forthcoming[c]). Retained removal action alternatives for the site are drawn from the Technology Technical Memorandum

and based on site-specific conditions and other local requirements. The removal action alternatives are:

- **Alternative 1: No Action** – No treatment or removal action would occur at the site. Consequently, all threats remain unchanged. Contaminated soils and mine waste would continue to threaten human and ecological receptors. Gamma radiation and any physical hazards would still be present.
- **Alternative 2: Consolidation and Capping** – Attains RAOs by excavating the burial cell contents, residual waste rock, and contaminated soils; consolidating the waste in a new burial cell; and capping the burial cell.
- **Alternative 3: Excavation, Transport, and Disposal in On-Navajo Nation Regional Repository** – Attains RAOs by excavating the burial cell contents, residual waste rock, and contaminated soils; hauling waste 6 miles (one way) to a nearby on-Navajo Nation regional repository; consolidating the waste in the repository; and capping the repository.
- **Alternative 4: Excavation, Off-Navajo Nation Transport, and Disposal at White Mesa Mill** – Attains RAOs by excavating the burial cell contents, residual waste rock, and contaminated soils; hauling waste 63 miles (one way) to the White Mesa Mill near Blanding, Utah, for uranium recovery; and disposing of the mill tailings in a tailing disposal facility.
- **Alternative 5: Excavation, Off-Navajo Nation Transport, and Disposal at Hazardous Waste or LLRW Facility** – Attains RAOs by excavating the burial cell contents, residual waste rock, and contaminated soils; and hauling waste 565 miles (one way) to and disposing of waste in the Clean Harbors hazardous waste disposal facility in Deer Trail, Colorado.

Retained removal action alternatives are fully described in [Section 4.2.2](#) and will be carried through a detailed analysis in [Section 4.3](#).

4.1.3 Applicable or Relevant and Appropriate Requirements

While CERCLA § 121(d) requires that remedial actions attain standards, requirements, criteria, or limitations that are determined to be ARARs, this section does not apply to removal actions and does not specifically require that removal actions attain ARARs. However, pursuant to NCP at 40 CFR § 300.415(j), USEPA has promulgated a requirement that removal actions attain federal and state ARARs to the extent practicable considering the exigencies of the situation. The ARARs evaluation completed for the Brodie I Mine was a comprehensive and complete evaluation of ARARs and no ARARs were rejected based on the exigencies of the situation. The Brodie 1 Mine is located on Navajo Nation land. Pursuant to NCP at 40 CFR § 300.5, the term “state” includes American Indian tribes. Therefore, for purposes of evaluating potential ARARs, tribal requirements will be treated the same as state requirements. The identification of ARARs is an iterative process; therefore, ARARs are referred to as potential until the final determination is made by USEPA in the action memorandum.

NCP at 40 CFR § 300.5 identifies ARARs and other “To Be Considered” (TBC) as follows:

- **Applicable requirements** are defined as “those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location or other circumstance found at a CERCLA site.”
- **Relevant and appropriate requirements** are defined as “those cleanup standards, standards of control, and other substantive requirements, criteria, or limitation promulgated under federal or state environmental or facility siting laws that, while not ‘applicable’ . . . address problems or situations sufficiently similar to those encountered at the CERCLA site and that . . . is well suited to the particular site.”
- **TBC criteria** consist of advisories, criteria, or guidance that were developed by USEPA, other federal agencies, or states that may be useful in developing CERCLA remedies and include non-promulgated guidance or advisories that are not legally binding and that do not have the status of potential ARARs. TBCs generally fall within three categories: health effects information with a high degree of credibility, technical information on how to perform or evaluate site investigations or response actions, and policy.

Factors to be considered when determining if requirements meet the criteria for applicable or relevant and appropriate requirements are discussed in the “Navajo Nation Abandoned Uranium Mines Applicable or Relevant and Appropriate Requirements Technical Memorandum” (ARARs Technical Memorandum) (USEPA, Forthcoming).

ARARs apply to onsite actions completed as part of the removal action. The onsite actions evaluated in this AAM will occur exclusively on Navajo Nation land. Therefore, the State of Arizona lacks regulatory jurisdiction, and State of Arizona statutory or regulatory requirements are not evaluated as potential ARARs (USEPA 1989a). Compliance with ARARs requires compliance only with the substantive requirements contained within the statute or regulation and, pursuant to CERCLA § 121(e)(1), does not require compliance with procedural requirements, such as permitting or recordkeeping. ARARs do not apply to offsite and off-Navajo Nation response actions. Instead, offsite and off-Navajo Nation response actions must only comply with independently applicable requirements (not relevant and appropriate) and must comply with both substantive and procedural components of the requirements.

USEPA, as the lead agency, is responsible for identifying potential federal ARARs and evaluating potential tribal ARARs identified by the Navajo Nation. For a tribal requirement to be identified as a potential ARAR, the requirement must be more stringent than federal ARARs.

USEPA has divided ARARs into three categories: chemical specific, location specific, and action specific. The three categories are described below:

- **Chemical-Specific ARARs** are usually health- or risk-based numerical values or methodologies that, when applied to site-specific conditions, result in the establishment of numerical values. These values establish the acceptable amount or concentration of a chemical that may be found in, or discharged to, the ambient environment.

- **Location-Specific ARARs** apply to the geographical or physical location of the site. These requirements limit where and how the response action can be implemented.
- **Action-Specific ARARs** include performance, design, or other controls on the specific activities to be performed as part of the response action for a site.

The potential ARARs for this response action are presented in [Table 13](#), [Table 14](#), and [Table 15](#) by ARAR category and address site- and alternative-specific requirements specific to the Brodie 1 Mine. A full description and analysis of potential ARARs is presented in the ARARs Technical Memorandum (USEPA, Forthcoming).

4.2 DESCRIPTION OF ALTERNATIVES

Retained removal action alternatives for the Brodie 1 Mine are listed below along with a summary of common site construction and restoration elements applicable to all alternatives. A detailed description of removal action alternatives and associated costs, which focuses on the different waste disposal options, is presented in [Section 4.2.2](#).

4.2.1 Summary of Alternatives and Common Elements

The removal action alternatives for the Brodie 1 Mine are:

- Alternative 1: No Action
- Alternative 2: Consolidation and Capping
- Alternative 3: Excavation, Transport, and Disposal in On-Navajo Nation Regional Repository
- Alternative 4: Excavation, Off-Navajo Nation Transport, and Disposal at White Mesa Mill
- Alternative 5: Excavation, Off-Navajo Nation Transport, and Disposal at Hazardous Waste or LLRW Facility

4.2.1.1 Common Elements

To reduce repetitive discussion in the detailed alternative analyses, common removal action elements for Alternatives 2 through 5 are provided below.

Site Preparation. Laydown areas will be established near the regional repository or the Brodie 1 Mine site, depending on the alternative chosen ([Figure 19](#)). Laydown areas include port-a-potties, wash water, refuse pickup, decontamination station, temporary offices, temporary Wi-Fi and radio, and potentially a construction water well and tank stand. The laydown areas will also include security personnel and temporary fencing and signage for access controls. Laydown areas will remain until completion of the remedy.

No power is available at the site. Therefore, power for the project will be provided by diesel generators for the temporary work site (laydown) and well site location (if constructed). The diesel generators will require bulk fuel storage at the laydown area, as well as daily storage on

the project site. The generators will provide power for various types of construction equipment, lighting systems, and pumps.

A sufficient water supply is not available for construction near the site. Purchase of water from NTUA or construction of a new construction supply well near the Block K Mine regional repository will be needed to provide water for the project. Utility water could be obtained from NTUA hydrants in the area depending upon existing infrastructure and the volume of water available. Well depths will likely range from 600 to 900 feet if utility water is not available. Generators for site power will be used to run the well pump. A water storage tank for the water trucks will also be required. If a well is constructed, it could be left for use by the Navajo community for irrigation or livestock.

Cultural and Biological Exclusion and Timing. Cultural resource investigations were completed within the Brodie 1 Mine boundary in 2018 by Dinetahdoo Cultural Resources Management LLC. The presence of cultural and biological resources could impose limitations on removal actions. Culturally significant sites were observed in the northeast of the site and must be avoided during construction. No threatened and endangered species were identified at the site, and the project area does not have habitat suitable for sensitive species (Tetra Tech 2019).

Site Access. The Brodie 1 Mine is located in a fairly flat area. A sandstone ledge runs approximately northeast to southwest at the site preventing access from upslope. The waste pile and burial cell are located below the sandstone ledge. The site waste pile and burial cell on the lower portion of the site are easily accessible from an existing 2-mile long dirt road in the valley below the mine. The upper area of the site is accessible from Indian Route 35. Lower access road repair and maintenance, including grading of uneven surfaces, would be necessary. Upper access would involve extending an existing dirt road 0.7 mile across the outcropping Morrison Formation. [Figure 20](#) shows the site road access. Fencing would not be required during removal activities; however, access to the work area will be marked and signed. Traffic controls will not be required for ingress and egress at Indian Route 35.

Air Monitoring. A sampling and analysis plan would be prepared that describes the methods and procedures for collecting, analyzing, and evaluating air samples within and at the perimeter of work zones. A minimum of three air monitoring stations would be positioned and operated to monitor dust and airborne contaminant concentrations during grubbing, excavation, stockpiling, loading of trucks, and site restoration. Air monitoring results would be used to document that onsite and offsite migration of contaminants at unacceptable concentrations does not occur. Workers in close proximity to dirt moving and loading activities would also wear real-time dust monitoring equipment to identify the need for respiratory protection upgrades.

Dust Control. Off-road haul routes and site excavation and restoration areas would be wetted to minimize dust generation. Frequent water spraying would be used during soil moving activities at all work zones for dust suppression. Further, rock fields and grating will be used to reduce track out of dirt onto paved surfaces. Water used for dust control and cleaning of paved surfaces will be imported or pumped from a new construction well as described above. Dust control will be used to maintain compliant air quality conditions and a safe working environment and will also protect the health of nearby residents, workers, the general public, and the environment.

Excavation Approach. Waste rock within the burial cell, unreclaimed waste rock, and contaminated soils at the reclaimed waste pile are the removal areas of concern (Figure 21). The approximately 1,300 cubic yards of waste is easily accessed. Waste excavation methods considered for the Brodie 1 Mine include standard size excavators and loaders. Waste removed from the burial cell along with excavated unreclaimed waste rock and contaminated soils will be temporarily stockpiled for load out or placement in a new onsite burial cell. Borrow fill will consist of material excavated to prepare a new burial cell or repository site to receive waste. Borrow will be used for cover material for the onsite and on-Navajo Nation disposal alternatives. If additional borrow is required to restore excavated waste piles and areas of contaminated soil, nearby areas will be used to create borrow areas.

Waste Handling and Transfer. For Alternative 2 (Consolidation and Capping), waste will remain on site and will be moved using a loader or a 10-ton end dump truck because of traffic concerns within a small work area. For Alternative 3 (Regional Repository), waste will be loaded into 25-ton articulated dump trucks and hauled 6 miles to the regional repository near the Block K Mine. For Alternatives 4 and 5 (Off-Navajo Nation Disposal), waste will be direct loaded into covered 25-ton on-highway haul trucks. The haul trucks will proceed to Indian Route 35 via a short dirt road. No transfer station will be required because the site can be accessed with multiple types of trucks. Dry brushing of all truck bed and wheels will occur before each truck leaves the site.

Cap Design Assessment. Containment in a burial cell or regional repository (Alternatives 2 and 3) would involve the construction of an engineered cap over the consolidated mine waste. Two types of engineered caps were evaluated through infiltration and radon flux modeling in the Technology Technical Memorandum (Tetra Tech, Forthcoming[c]) for waste containment: a soil ET cap and a soil cap containing an integral high-density polyethylene (HDPE) liner.

A total of 36 inches of cover is required for an ET cap to prevent infiltration of precipitation and snowmelt, control radon gas flux, and reduce gamma activity to background. A cap with an HDPE liner would require less soil cover; however, 24 inches of cover would still be needed to protect the liner from frost heave.

Both engineered cap types would minimize the vertical migration of precipitation and snowmelt to and contact with underlying mine waste. However, an ET cap would allow for slow dissemination and natural degradation of radon gas while a soil cap with an HDPE liner would tend to trap radon gas, which may find preferential pathways for a release at higher concentrations.

Because of the remoteness of the Navajo Nation and the Tse Tah region, the cap material, trucking, and installation costs for the two different cap options should also be considered along with the impacts on construction schedule, transportation, and labor requirements. Overall, use of nearby borrow soil for cover material reduces trucking costs and the project schedule; however, if borrow soil is limited, a soil cap with HDPE liner may become more cost effective.

For the Brodie 1 Mine, an ET cap would be preferable for the Alternative 2 burial cell because the waste is not leachable, soil borrow material for the cover is readily available and the cover size is small. A cap with a HDPE liner may be considered for the regional repository location

near the Block K Mine if higher concentration or leachable waste from other sites is consolidated at the repository.

Site Restoration Activities. Areas disturbed by mining and removal activities will require restoration. The upper area of the site is naturally exposed bedrock shelves comprising Salt Wash Member of the Morrison Formation of the Morrison Formation. The upper area was identified as NORM and has not been disturbed by mining activities. Access may be required on the upper area for construction of run-on controls to protect the remedy on the lower portion of the site. The disturbed areas will require restoration.

USEPA has developed a matrix in the “Navajo Nation Abandoned Uranium Mines Surficial Restoration Approaches Technical Memorandum” (Tetra Tech, Forthcoming[d]) to identify different features and areas of mine sites requiring restoration and the corresponding typical restoration approaches. [Table 16](#) identifies the mine features and areas present at the Brodie 1 Mine along with general restoration approaches. Further details regarding each feature and area requiring restoration are described below:

- *Lower Access Road.* A 2-mile dirt road already exists from Indian Route 35 to the lower Brodie 1 Mine site ([Figure 22](#)). A short, 0.2-mile temporary access road constructed from the end of the dirt road to the main part of the site will be obliterated and the land restored. The road pathway will be contour graded to match surrounding grade and seeded using local grasses and forbes. A soil berm will be used to block vehicular access. Any construction-related damage to the existing dirt road will be repaired, which may involve grading, repair of water crossings, and repair of drainage ditches.
- *Upper Site Access.* A dirt road already exists from Indian Route 35 to approximately 0.7 mile from the upper Brodie 1 Mine site ([Figure 22](#)). A short, temporary access road, if needed to install run-on controls, from the end of the dirt road to the upper site will be obliterated and the land restored. The road pathway will be contour graded to match surrounding grade and seeded using local grasses and forbes. Any construction-related damage to the existing dirt road will be repaired, which may involve grading and repair of drainage ditches.
- *Mine Portal.* The portal has already been closed by NAML RD ([Figure 22](#)). However, dry stacked rock placed in front of the concrete block closure has been disturbed. The rock will be restacked and grouted in place. Further, rock will be stacked on the edge of the bedrock shelf to limit access to the portal area.
- *Boreholes and Vent Shafts.* No boreholes or vent shafts were identified during a review of historical documents and during the RSE.
- *Burial Cell.* NAML RD constructed a temporary burial cell at the site ([Figure 22](#)). Under all alternatives, the existing burial cell will be excavated because of encroachment by a headward-cutting drainage channel. The burial cell area will be restored as an excavated area as described below.
- *Waste Excavation Areas.* Excavated areas will be backfilled with soil from a local borrow area and contour graded to match adjacent topography along the toe of the cliff ([Figure 22](#)). The area within the drainage pathway from the upper site will be graded to flow into the headward-cutting drainage. The drainage pathway from the toe of the cliff

to the headward-cutting drainage will be excavated to form a channel and lined with rock. The remainder of the graded surface along the toe of the cliff will be covered with biodegradable matting and seeded using local grasses and forbs. Temporary 4-strand barbed wire fencing will be erected around the restored area (site and borrow area) to protect revegetation efforts from grazing over a period of up to 10 years.

- *Runoff from the Upper Site.* Sheet flow runoff from the upper site will be intercepted and diverted to the upper site drainage pathway using a rock and soil berm (Figure 22). NAMLRD already constructed a low berm on the upper site, which would be lengthened and fortified to increase base width and height.
- *Headward-Cutting Drainage.* A tributary to the Tse Tah West Wash receives runoff from the upper site and a small portion of the lower site. The channel will be extended 170 feet to the base of the cliff. Both the extended and a 95-foot portion of the existing channel will be lined with riprap to dissipate energy and reduce erosion (Figure 22).

Short-Term Operation and Maintenance of Site Restoration Features. Operation and maintenance (O&M) for restored excavation areas, obliterated temporary roads, and restored borrow areas. Annual O&M will include:

- Vegetation survey in late spring
- Erosion control inspection and maintenance survey after the monsoon season
- Vegetation maintenance includes reseeding and removing weeds
- Repairs to range fencing, erosional features, and water control berms

At the end of site restoration period, accumulated soil in detention basins will be assessed to determine if material needs to be removed and placed in a repository or disposed of off site.

Burial Cell and Regional Repository Closure and Long-Term Operation and Maintenance. Activities common to Alternatives 2 (onsite burial cell) and Alternative 3 (regional repository) include:

- Final grading, surface erosion controls, and revegetation of the burial cell or regional repository cap will be designed to limit visual impact by mimicking local terrain and using local soils and vegetation (Figure 23 and Figure 24).
- Erosion controls on the cap may include biodegradable matting and wattles and using berms and ditches to direct run-on water around the burial cell or regional repository and to collect runoff from the burial cell or repository in a detention basin before discharge (Figure 23 and Figure 24).
- Permanent range fencing will be installed around the burial cell and regional repository to control or restrict grazing and access since overgrazing, livestock foot traffic, or vehicle traffic could damage the cap.

Land use controls would be required for waste placed in a burial cell or repository to protect the remedy. The form of the land use controls would likely be a land withdrawal or an

environmental covenant, such as an easement to restrict future residential use or activities that would disturb the cap.

Annual inspections and maintenance of the burial cell and regional repository covers will be conducted as specified in an O&M plan with inspection frequencies adjusted based on the cover stability and inspection findings. Inspections would consist of checking for erosion and burrowing and verifying the integrity of erosion controls. Maintenance will consist of filling burrows, filling and grading eroded surfaces, clearing accumulated erosion materials, replanting vegetation, and repairing access roads. Periodically, accumulated soil in detention basins will be assessed to determine if material needs to be removed and placed in a repository or disposed of off site. O&M costs were developed based on a 1,000-year duration (required under UMTRCA 40 CFR § 192[d] Part A) for the earthen covers placed on top of radiological waste contained within a burial cell or repository.

4.2.1.2 Potential Unavoidable Impacts

Except for Alternative 1 (no action), each of the removal action alternatives would result in an overall improvement to the local environment. However, for Alternatives 2 through 5, unavoidable impacts are expected and include:

- Existing vegetation in the lower Brodie 1 Mine area is limited to scrub and grasses while vegetation in the upper area also includes small trees. Construction activities will generally be limited to disturbance in the lower area, and the trees in the upper area will be avoided as much as possible during construction. Disturbed areas will be reclaimed after construction, but reestablishing the existing vegetation will take time.
- Inconvenience to local populations using Indian Route 35; general disturbance to local residents from heavy equipment activity for the 1- to 2- month construction period; and increased truck traffic on the lower dirt access road, Indian Route 35, and the access road to the regional repository near the Block K Mine. Generation of dust on access roads would be minimized through spraying with water during construction and hauling activities. Noise will be limited to normal work hours to avoid disturbing local residents.
- Disruption of sensitive species and habitat during construction activities is not anticipated at the Brodie 1 Mine or regional repository near the Block K Mine. If sensitive species are subsequently identified during a biological survey, the timing of construction activities will be adjusted to limit disturbance and biological monitoring will be conducted during construction activities.
- Cultural resources were potentially identified near the Brodie 1 Mine. A cultural resource specialist will be consulted during removal design to ensure that any proposed construction activities will avoid sensitive areas. Cultural resource monitors will be on site during construction activities to ensure resources are not disturbed. A cultural resource survey has not been completed at the proposed repository site near Block K Mine.
- Disruption of wildlife and livestock access to the restored site for an estimated 10 years after completion of site work to establish and stabilize vegetation. Livestock access to

burial cell or repository covers may also be restricted, depending on cap design, to prevent damage to cap.

- Increased risk of traffic accidents and fatalities and greenhouse gas emissions because of the trucking of fill, cover material, and waste. As the haul distance increases, the potential risks also increase.

4.2.2 Description of Removal Action Alternatives

The following subsections present descriptions of the five removal action alternatives identified in [Section 4.1](#).

4.2.2.1 Alternative 1: No Action

Under Alternative 1, radionuclide and metal COCs and COECs in the burial cell, waste pile, and surrounding soils would not be addressed. No land use controls, signage, range fencing, or barriers would be used to limit access at the Mine. No removal or site stabilization activities would occur.

4.2.2.2 Alternative 2: Consolidation and Capping

Under Alternative 2, the RAOs would be accomplished through excavation of an existing burial cell and waste rock piles and containment of waste in a new onsite burial cell ([Figure 21](#) and [Figure 23](#)). Approximately 1,300 cubic yards of waste from the Brodie 1 Mine would be excavated and placed in a new onsite burial cell location immediately north of the existing burial cell in an area already impacted by mining activities. The site is easily accessible from the site access road, which would require minor improvements, such as widening and grading, to accommodate construction traffic as necessary ([Figure 20](#)).

The new burial cell would be protected from erosion through armoring the headward-cutting drainage channel below the mine and surface water diversion berms and ditches above the burial cell. Other components of the alternative include repair of the mine portal closure, implementation and short-term O&M of site restoration measures, and land use and access controls to protect the burial cell cover and site restoration process ([Figure 22](#)). Site excavation and restoration elements common to alternatives are described in [Section 4.2.1.1](#).

The soils at the site are primarily loamy fine sands over bedrock (U.S. Department of Agriculture 2018). Waste to be placed in the burial cell is typically a mix of rocks in a fine sand matrix, is non-acid generating based on acid-base accounting (ABA) testing, and exhibits low metals leachability based on synthetic precipitation leaching procedure (SPLP) results. Based on SPLP testing, leachable concentrations of aluminum and lead in mine waste exceeded water quality criteria for ecological receptors; however, neither metal was identified as a COPC or COPEC. Ra-226 was detected but did not exceed water quality standards.

Based on an assessment of depth to bedrock (at least 10 feet), volume of waste, available area (approximately 6,000 square feet), low concentrations of radionuclides and metals in the waste, non-acid generating and low leachability properties of the waste, and minimum thickness of engineered cap from the hydrologic evaluation of landfill performance (HELP) and RADON

model results presented in the Technology Technical Memorandum (Tetra Tech, Forthcoming[c]), a 36-inch thick ET cap would be the preferred cover for the new burial cell.

The new 6,000-square-foot burial cell will be excavated to a depth of 10 feet or bedrock (Figure 23). Excavated soil will be stockpiled for use as cover and for site restoration. Waste will be placed in the cell and compacted in 6-inch lifts to a depth of 3 feet below grade. The 36-inch thick ET cap will be constructed using onsite loamy fine sand soils augmented with imported gravel to improve erosion resistance. The ET cap would require approximately 800 cubic yards of cover soil. Ventilation is not required for radon-222 as the modeled flux within the waste would never exceed the 20 picocurie per meter squared per second (pCi/m²-sec) limit for flux to atmosphere (Tetra Tech, Forthcoming[c]).

Design considerations to limit the visual impact of the ET cap include grading and contouring into an existing toe of slope below the cliff. The top of the cap will be graded to achieve a 3 to 5 percent slope for surface drainage. Biodegradable matting and wattles would be placed on the cap and other restored areas to limit erosion. Surface controls would involve directing run-on water around the burial cell and other restored areas using an upslope berm and ditches. Borrow soil for restoration of the remainder of the site will be obtained from both reserves from the new burial cell pit and an area adjacent to the site with the same soil type. The ET cap and surrounding restored areas will be revegetated with native grasses and forbs to blend in with the landscape. Permanent range fencing will be constructed around the burial cell to control or restrict grazing and access since overgrazing, livestock foot traffic, or vehicle traffic could damage the cap.

Other site restoration activities include access road closure, mine portal closure repair, backfilling and grading of waste excavation areas, and armoring the headward-cutting drainage channel below the mine site. Site restoration activities are described further in Section 4.2.1.1. Post-removal visualizations of the burial cell and restored Brodie 1 Mine site are included in Appendix D.

Excavation and consolidation of waste rock in an onsite burial cell and implementation of surficial restoration activities and land use controls would be performed as a single removal action. Figure 21 and Figure 23 show the proposed waste excavation, burial cell, and restoration areas at the site. Implementation of Alternative 2 would involve the removal action components described below.

Removal Action Components

Additional information regarding individual components is provided in Section 4.2.1.1.

- Procurement of water from the NTUA pipeline along Indian Route 35 or construction of a water well (shared cost with the Block K Mine) if NTUA water cannot be accessed
- Rehabilitation and widening of the Brodie 1 Mine lower access road
- Excavation and stockpiling of clean soil from the new burial cell location
- Excavation of waste and contaminated soil from the existing burial cell, unreclaimed waste rock piles, and other areas exceeding cleanup goals

- Consolidation and compaction of waste in the new burial cell
- Construction of the ET cap over the new burial cell
- Implementation of site restoration measures (channel stabilization and run-on and erosion controls)
- Implementation of access controls, such as permanent range fencing to control or restrict grazing and access since overgrazing, livestock foot traffic, or vehicle traffic could damage the cap
- Restoration of excavated surfaces and removal of temporary access roads
- Excavation, lengthening, and stabilization of the headward-cutting drainage channel at the Brodie 1 Mine to connect with the natural drainage from the upper mine site
- O&M of surficial restoration areas
- O&M of the ET cap

Cost Estimate

The total net present value for consolidation and capping of approximately 1,300 cubic yards of waste at the Brodie 1 Mine is \$3,099,496. This includes a capital cost of \$2,240,257, annual O&M costs of \$24,646 over 10 years for site restoration, and annual O&M costs of \$22,899 over 1,000 years for the access road and burial cell ET cap.

4.2.2.3 *Alternative 3: Excavation, Transport, and Disposal in On-Navajo Nation Regional Repository*

Under Alternative 3, the RAOs would be accomplished through excavation, hauling, and consolidation of waste in a regional repository located near the Block K Mine on lands that are already impacted by mining activities; containment of waste in the repository; repair of the mine portal closure; implementation and short-term O&M of site restoration measures and land use and access controls to protect the repository and site restoration process ([Figure 21](#) and [Figure 24](#)). Site excavation and restoration elements common to alternatives are described in [Section 4.2.1.1](#).

Approximately 1,300 cubic yards (about 100 truckloads) of waste from the Brodie 1 Mine would be hauled approximately 6 miles to a regional repository located near the Block K Mine ([Figure 21](#)). The regional repository will be in an accessible area where year-round access for maintenance, economy of scale, and lower overall O&M costs would be realized, which may be preferable to an isolated onsite burial cell at the Brodie 1 Mine site. Site restoration activities include access road closure, mine portal closure, backfilling and grading of waste excavation areas, erosion controls, controlling runoff from the upper mine site, and armoring the headward-cutting drainage channel below the mine site ([Figure 22](#)). Site restoration activities are described further in [Section 4.2.1.1](#). Post-removal visualizations of the restored Brodie 1 Mine site are included in [Appendix D](#).

The proposed regional repository location is in a mining disturbed area (drilled and explored extensively) within a mine lease boundary and is considered on site under CERCLA. The

proposed regional repository will be located 1.4 miles southwest of the Block K Mine in the Sweetwater Chapter. The potential regional repository location was selected to limit visibility from the Teec Nos Pos community and Highway 160. Design considerations to limit visual impact include reduced height, grading to look like a low hill and contouring into an existing hillslope, and use of local soils and small rocks within the cover to better blend in with the surroundings. The repository cap will comprise native soil and a gravel admixture and will be revegetated to blend in with the landscape. Permanent range fencing will be constructed around the repository to control or restrict grazing and access since overgrazing, livestock foot traffic, or vehicle traffic could damage the cap. Post-removal visualizations of the restored Brodie 1 Mine site are included in [Appendix D](#).

The regional repository construction and O&M costs are based on the volume of waste contributed to the repository from the Tronox mines located in the Teec Nos Pos and Sweetwater Chapters. The cost share is 77 percent for the Block K Mine and 23 percent for the Brodie 1 Mine based on waste volume contribution (approximately 4,400 and 1,300 cubic yards, respectively). Waste from other Tronox and non-Tronox AUMs in the Teec Nos Pos Region could also be placed in the regional repository and would reduce the costs for construction borne by both Block K Mine and Brodie 1 Mine.

Combined Actions under CERCLA - CERCLA § 104(d)(4) allows USEPA to treat noncontiguous facilities as on site for the purpose of taking actions when the facilities are related geographically, or on the basis of the threat or potential threat to the public health or welfare. This means waste from several Superfund sites can be managed in a coordinated fashion at one of the sites and still be an “onsite” action. For example, an alternative that involves consolidation of Brodie 1 Mine waste at another Tronox mine or in a mining disturbed area (drilled and explored extensively) within a mine lease boundary would be a coordinated onsite action with other Tronox mines in the Tse Tah region under CERCLA § 104(d)(4). The Brodie 1 Mine and the other Tronox mines are related geographically, have the same potentially responsible party, and have similar waste and risk characteristics.

Regional Repository Siting Assessment

An on-Navajo Nation regional repository containing unprocessed uranium mine waste may be constructed and used without obtaining a license from the Nuclear Regulatory Commission (NRC) as specified in the Atomic Energy Act (AEA) § 62. Inclusion of wastes from non-Tronox mines within the Teec Nos Pos and Sweetwater Chapters would require negotiation with USEPA, other potentially responsible parties, and the Navajo Nation.

The regional repository location was selected based on ease of access and ability to service multiple nearby AUMs. The repository is located 1.3 miles southwest of the Block K Mine. The access road would require minor revisions, such as widening and grading, to accommodate the amount of haul traffic ([Figure 24](#)). The repository is also centrally located between the Mesa V, Mesa VI, and Mesa IV Mine sites.

AEA at 10 CFR Part 40, [Appendix A](#), Criteria 1 and 4, identifies the uranium mill tailings disposal site selection and design criteria to be considered for the proposed regional repository

site. The AEA criteria and relevant regional repository site and design considerations were evaluated by desktop study and are provided below:

- **Remoteness:** The site would be located in a remote area away from the Teec Nos Pos and Red Mesa communities.
- **Natural conditions that contribute to continued immobilization and isolation of contaminants from groundwater sources:** The site would be located approximately 600 to 900 feet above the local drinking water aquifer with two regional aquitards and the uranium ore-bearing Morrison Formation separating the proposed repository site from the drinking water aquifer.
- **Potential for minimizing erosion, disturbance, and dispersion by natural forces:** The site would be located near the toe of a mesa with topography sloping away from the proposed repository.
- **Disposal in a manner that no active maintenance is required to preserve site conditions:** The site would be located where natural topography and drainage away from the site would minimize the need for long-term maintenance after native vegetation is established. A NAML RD demonstration repository is located nearby the site ([Figure 24](#)). Control of runoff from a nearby mesa top would need to be established; however, a natural drainage is located between the site and mesa toe.
- **Topographic features that provide good wind protection:** The site would be located in a box canyon between two mesa arms. The waste and ET cap top and side slopes would be graded to match the surrounding topography.
- **Relatively flat cover slopes to minimize erosion:** The waste placed into the hillslope and cover would be graded to minimize the height of the side slopes.
- **Full self-sustaining vegetative or rock cover to reduce wind and water erosion:** Gravel admixture would be included in the upper 6 inches of soil of the cap and native vegetation would be used to minimize erosion.
- **Location away from a fault that could cause a maximum credible earthquake larger than what the impoundment could reasonably withstand:** No major active faults are located near the site.
- **Incorporation of features that promote deposition where feasible:** Drainage swales and a downslope sediment detention basin would be used to minimize soil migration during the establishment of vegetative cover at the repository.

The soils at the regional repository area are loamy fine sands over bedrock. Waste to be placed in the regional repository is typically a mix of rocks in a fine sand matrix, is non-acid generating based on ABA testing, and exhibits low metals leachability based on SPLP results. Based on SPLP testing, leachable concentrations of aluminum and lead in mine waste exceeded water quality criteria for ecological receptors; however, neither metal was identified as a COPC or COPEC. Leachable Ra-226 did not exceed water quality standards.

Based on an assessment of depth to bedrock (at least 6 feet), medium volume of waste, available area (approximately 34,000 square feet), non-acid generating and low leachability properties of the waste, and minimum thickness of engineered cap determined using the HELP and RADON

models as presented in the Technology Technical Memorandum (Tetra Tech, Forthcoming[c]), an ET cap would be the preferred cap for the regional repository as the mine waste contains low total and leachable concentrations of radionuclides and metals. A 36-inch thick ET cap would require approximately 3,800 cubic yards of cover soil.

The 34,000-square-foot repository would be constructed by excavating and stockpiling the top 6 inches of soil as topsoil, excavating and stockpiling the remaining soil to bedrock as borrow, and rough grading the base of the repository to allow for vehicular traffic and receive waste. The top layer of the waste would be graded to achieve a 3 to 5 percent slope for surface drainage. Side slopes would be graded no steeper than a 5-foot-horizontal to 1-foot-vertical slope. The 36-inch thick ET cap would then be constructed on top of 7 feet of waste with a topsoil and gravel admixture being used for the final 6 inches of the cap. Biodegradable matting and wattles would be placed on the cover top and side slopes to limit erosion of the cover. Surface controls would involve directing run-on water around the repository using berms and ditches. Ventilation is not required for radon-222 as the modeled flux within the waste is below 20 pCi/m²-sec. Post-removal visualizations of the regional repository are included in [Appendix D](#).

Excavation and disposal of waste rock in an on-Navajo Nation repository and implementation of surficial restoration activities and land use controls would be performed as a single removal action. [Figure 21](#) and [Figure 22](#) show the proposed waste excavation and restoration areas at the Brodie 1 Mine. For Alternative 3, waste will be transported to and disposed of at the regional repository near the Block K Mine. [Figure 24](#) shows the proposed 1.4-mile haul route from the mine to the regional repository. Implementation of Alternative 3 would involve the removal action components described below.

Removal Action Components

Additional information regarding individual components is provided in [Section 4.2.1.1](#).

- Rehabilitation and widening of the Brodie 1 Mine access road
- Excavation of waste and contaminated soil from the existing burial cell, unreclaimed waste rock piles, and other areas exceeding cleanup goals
- Load out and haul of waste to the new regional repository near the Block K Mine
- Disposal of waste at the new regional repository
- Implementation of site restoration measures (channel stabilization and run-on and erosion controls)
- Implementation of access controls, such as temporary range fencing to exclude grazing over the short term, to allow successful revegetation
- Restoration of excavated surfaces and removal of temporary access roads
- O&M of surficial restoration areas

Regional Repository Construction Components

Additional information regarding individual components is provided in [Section 4.2.1.1](#).

- Rehabilitation and widening of the main haul road from Indian Route 35 to the regional repository
- Construction of a water well at the repository (shared repository cost) if NTUA water cannot be accessed
- Construction and filling of the repository (shared repository cost). Interim capping or filling of the repository by cell where filling does not occur in a single season.
- Closing the repository with an ET cap (shared repository cost)
- Implementation of access controls, such as permanent range fencing to exclude grazing over the short term, to allow successful revegetation on the ET cap
- O&M of the ET cap

Cost Estimate

The total net present value for consolidation and capping of approximately 1,300 cubic yards of waste at the regional repository is \$2,703,132. This includes a capital cost of \$2,030,876, annual O&M costs of \$24,646 over 10 years for site restoration, and annual O&M costs of \$16,349 over 1,000 years for the access road and regional repository ET cap.

4.2.2.4 Alternative 4: Excavation, Off-Navajo Nation Transport, and Disposal at White Mesa Mill

Under Alternative 4, the RAOs would be accomplished through excavation, transport, milling of waste rock and uranium-contaminated soil for uranium recovery, and disposal of mill tailings in the off-Navajo Nation White Mesa Mill tailings disposal facility. The site would be reclaimed through implementation of site restoration measures followed by short-term O&M of restored features and use of access controls to protect the site restoration process. Site excavation and restoration elements common to alternatives are described in [Section 4.2.1.1](#).

Approximately 1,300 cubic yards (about 100 truckloads) of waste from the Brodie 1 Mine would be hauled off the Navajo Nation to an operating uranium mill and associated tailings disposal facility ([Figure 21](#)). The hauling of waste will comply with permitting requirements for the transport of radioactive materials. The facility is the Energy Fuels, Inc. White Mesa Mill facility located near Blanding, Utah, 63 miles from the Brodie 1 Mine ([Figure 25](#)). The White Mesa Mill facility is regulated as a uranium mill and tailings disposal facility under NRC regulations in 10 CFR Part 40, [Appendix A](#), by the State of Utah as an Agreement State under AEA.

Site restoration activities include access road closure, mine portal closure, backfilling and grading of waste excavation areas, erosion controls, controlling runoff from the upper mine site, and armoring the headward-cutting drainage channel below the mine site ([Figure 22](#)). Site restoration activities are described further in [Section 4.2.1.1](#). Post-removal visualizations of the restored Brodie 1 Mine site are included in [Appendix D](#).

The White Mesa Mill tailings disposal facility has a 3-million-ton capacity and is permitted an additional 4 million tons. At the time of this AAM preparation, the facility is in compliance with its State of Utah operating license, bonding, and the CERCLA Off-Site Rule. A change to the disposal facility could be selected in the action memorandum if necessary. Coordination of waste batches for mill operations would require negotiation between USEPA, other potentially responsible parties, White Mesa Mill operators, and the Navajo Nation.

In general, the CERCLA Off-Site Rule requires that facilities that accept contaminated or hazardous wastes from a CERCLA site must follow all applicable regulations and laws (that is, they must be approved to take those wastes and be in compliance with the applicable federal, state, and local requirements to do so). The licensed disposal facilities considered for any alternatives involving offsite disposal would be required to have existing regulatory approval under the Off-Site Rule.

Although AUM ore material is classified as TENORM by USEPA, the source material license issued by the State of Utah allows the White Mesa Mill to process natural uranium ores. NRC has determined that a material is considered to be ore if there is a reasonable expectation that uranium can be recovered from the material even if it is low grade and not profitable, and the mill would receive a fee to process the material (Energy Fuels, Inc. 2018). Contaminated debris associated with the ore has been regulated as ore (NRC 2000 as cited in Energy Fuels, Inc. 2018). Based on these determinations, the White Mesa Mill can accept overburden, waste rock, proto ore, and other ore-related waste materials for processing through the mill. Resulting wastes associated with processing then become 11e(2) byproduct material and can be disposed of in the mill tailings disposal facility. If and when the mill and associated tailings disposal facility source material license is terminated, ownership of the tailings disposal facility will be transferred to the U.S. Department of Energy, which will be responsible for long-term surveillance, care, and maintenance.

Excavation, milling, and disposal of waste rock in an off-Navajo Nation mill facility and implementation of surficial restoration activities and access controls would be performed as a single removal action. [Figure 21](#) and [Figure 22](#) show the proposed waste excavation and restoration areas at the Brodie 1 Mine. For Alternative 4, waste will be transported to and disposed of at the White Mesa Mill facility near Blanding, Utah. [Figure 25](#) shows the proposed 63-mile haul route from the mine to the White Mesa Mill facility. Implementation of Alternative 4 would involve the removal action components described below.

Removal Action Components

Additional information regarding individual components is provided in [Section 4.2.1.1](#).

- Rehabilitation and widening of the Brodie 1 Mine access road
- Excavation of waste and contaminated soil from the existing burial cell, unreclaimed waste rock piles, and other areas exceeding cleanup goals
- Load out and haul of waste to the White Mesa Mill near Blanding, Utah
- Off-Navajo Nation waste milling and disposal at the White Mesa Mill near Blanding, Utah

- Restoration of excavated surfaces and removal of temporary access roads
- Implementation of site restoration measures (channel stabilization and run-on and erosion controls)
- Implementation of access controls, such as temporary range fencing to exclude grazing over the short term, to allow successful revegetation
- O&M of surficial restoration areas

Cost Estimate

The total net present value transportation and off-Navajo Nation milling and disposal of approximately 1,300 cubic yards of waste at the White Mesa Mill outside of Blanding, Utah, is \$2,263,058. This includes a capital cost of \$2,058,075 and annual O&M costs of \$24,646 over 10 years for site restoration.

4.2.2.5 Alternative 5: Excavation, Off-Navajo Nation Transport, and Disposal at Hazardous Waste or Low-Level Radioactive Waste Facility

Under Alternative 5, the RAOs would be accomplished through excavation, transport, and off-Navajo Nation disposal of mine waste and contaminated soil. The site would be reclaimed through implementation of site restoration measures followed by short-term O&M of restored features and use of access controls to protect the site restoration process. Site excavation and restoration elements common to alternatives are described in [Section 4.2.1.1](#).

Approximately 1,300 cubic yards (about 100 truckloads) of waste from the Brodie 1 Mine would be hauled off the Navajo Nation and disposed of at a RCRA Subtitle C hazardous waste or Class A LLRW facility ([Figure 21](#)). The hauling of waste will comply with applicable state permitting requirements for the transport of radioactive materials.

Site restoration activities include access road closure, mine portal closure, backfilling and grading of waste excavation areas, erosion controls, controlling runoff from the upper mine site, and armoring the headward-cutting drainage channel below the mine site ([Figure 22](#)). Site restoration activities are described further in [Section 4.2.1.1](#). Post-removal visualizations of the restored Brodie 1 Mine site are included in [Appendix D](#).

The following facilities have licenses or permits that allow for acceptance of uranium mine waste:

- US Ecology, Grand View, Idaho: RCRA Subtitle C hazardous waste disposal facility located 700 miles from the site.
- Clean Harbors, Deer Trail, Colorado: RCRA Subtitle C hazardous waste disposal facility located 565 miles from the site.
- Energy Solutions, Inc., Clive, Utah: LLRW facility located 450 miles from the site.
- Waste Control Specialists, Andrews, Texas: LLRW facility located 618 miles from the site.

The Clean Harbors, Waste Control Specialists, and Energy Solutions RCRA Subtitle C hazardous waste and LLRW disposal facilities are in compliance with NRC, Colorado, Texas, and Utah operating permits and the CERCLA Off-Site Rule. The Clean Harbors RCRA Subtitle C hazardous waste disposal facility was identified as the most cost effective disposal facility and is located near Deer Trail, Colorado, 565 miles from the Brodie 1 Mine ([Figure 26](#)). A change to the disposal facility could be selected in the action memorandum if necessary. Alternative 5 differs from Alternative 4 in that no treatment by milling is included and, therefore, requires different final disposal facility type and location.

In general, the CERCLA Off-Site Rule requires that facilities that accept contaminated or hazardous wastes from a CERCLA site must follow all applicable regulations and laws (that is, they must be approved to take those wastes and be in compliance with the applicable federal, state, and local requirements to do so). The licensed disposal facilities considered for any alternatives involving offsite disposal would be required to have existing approval under the Off-Site Rule.

Disposal at a licensed RCRA Subtitle C hazardous waste or LLRW facility is a standard disposal method involving transport to and disposal at the applicable waste disposal facility. Licensed or permitted facilities are generally constructed to prevent the release of hazardous or radioactive materials and include engineered cells and liners that exceed requirements for municipal or commercial solid waste disposal facilities.

No toxicity characteristic leaching procedure metals results exceeded the toxicity characteristic levels. Therefore, the waste pile at the Brodie 1 Mine does not contain materials that would be designated as RCRA hazardous waste if disposed of at a RCRA-permitted disposal facility. No pretreatment of the waste would be required before disposal.

Excavation and disposal of waste rock in an off-Navajo Nation RCRA Subtitle C hazardous waste or Class A LLRW facility and implementation of surficial restoration activities and access controls would be performed as a single removal action. [Figure 21](#) and [Figure 22](#) show the proposed waste excavation and restoration areas at the Brodie 1 Mine. For Alternative 5, waste will be transported to and disposed of at the Clean Harbors RCRA Subtitle C hazardous waste disposal facility in Deer Trail, Colorado. The selected disposal facility could be changed in the action memorandum if necessary. [Figure 26](#) shows the proposed 565-mile haul route from the mine to the Clean Harbors facility. Implementation of Alternative 5 would involve the removal action components described below.

Removal Action Components

Additional information regarding individual components is provided in [Section 4.2.1.1](#).

- Rehabilitation and widening of the Brodie 1 Mine access road
- Excavation of waste and contaminated soil from the existing burial cell, unreclaimed waste rock piles, and other areas exceeding cleanup goals
- Loading out and hauling of waste to the Clean Harbors RCRA Subtitle C hazardous waste disposal facility near Deer Trail, Colorado

- Off-Navajo Nation disposal at the Clean Harbors RCRA Subtitle C hazardous waste disposal facility near Deer Trail, Colorado
- Restoration of excavated surfaces and removal of temporary access roads
- Implementation of site restoration measures (channel stabilization and run-on and erosion controls)
- Implementation of access controls, such as temporary range fencing to exclude grazing over the short term, to allow successful revegetation
- O&M of surficial restoration areas

Cost Estimate

The total net present value for transportation and off-Navajo Nation disposal of approximately 1,300 cubic yards of waste at the Clean Harbors RCRA Subtitle C hazardous waste disposal facility in Deer Trail, Colorado, is \$2,802,105. This includes a capital cost of \$2,597,122 and annual O&M costs of \$24,646 over 10 years for site restoration.

4.3 ANALYSIS OF ALTERNATIVES

As required by NCP and described in the “Guidance on Conducting Non-Time Critical Removal Actions under CERCLA” (USEPA 1993), retained removal action alternatives are evaluated individually against the following three broad criteria: effectiveness, implementability, and cost. The qualitative evaluation criteria and qualitative rating ranges are described below. The individual alternative analysis ranks the effectiveness, implementability, and cost of each alternative as very poor, poor, average, good, or very good for each criterion.

In addition, based on USEPA (2016) guidance, five key elements in greener cleanup activities should be considered throughout the remedy selection process. USEPA’s (2012) five key elements are to:

- Minimize total energy use and maximize renewable energy use
- Minimize air pollutants and carbon dioxide equivalent emissions
- Minimize water use and negative impacts to water resources
- Improve materials management and waste reduction efforts by reducing, reusing, or recycling whenever feasible
- Protect ecosystem services

The qualitative evaluation criteria and qualitative rating ranges are described below.

Effectiveness Criterion

This criterion evaluates protectiveness and compliance with ARARs, along with short- and long-term effectiveness and permanence, and reduction in toxicity, mobility, and volume of waste. Effectiveness was rated from very poor to very good.

- **Overall Protection of Human Health and the Environment** – This threshold criterion evaluates whether each alternative provides adequate protection of human health and the environment. The assessment of overall protection draws on the evaluation of long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

Evaluation of the overall protectiveness focuses on whether a specific alternative achieves adequate protection and how site risks posed through each pathway addressed by the AAM are eliminated, reduced, or controlled through treatment, engineering, or land use controls. Based on effectiveness and ARAR compliance, alternatives are either considered protective or not protective.

- **Compliance with ARARs** – This threshold criterion evaluates whether each alternative would meet the identified ARARs. The evaluation determines which requirements are applicable or relevant and appropriate to an alternative and how the alternative meets these requirements. Alternatives are either in compliance with ARARs or not in compliance.
- **Short-Term Effectiveness** – This criterion evaluates the effects that the alternative would have on human health and the environment during its construction and implementation phase. The evaluation includes both radiation risks from exposure to the contaminated soils and risks to the workers and communities from construction work, pollution, and traffic during implementation, and also takes into account the time necessary to complete the action. A greener cleanups analysis was completed to evaluate energy requirements, emissions, water resources, materials management, land management, and ecosystem protection. Short-term effectiveness was rated from very poor to very good.
- **Long-Term Effectiveness and Permanence** – This criterion evaluates the results of the removal action in terms of the risk remaining at the site after response objectives have been met. The primary focus of this evaluation is on the extent and effectiveness of the controls that may be required to manage the risk posed by wastes remaining at the site. Long-term effectiveness and permanence was rated from very poor to very good.
- **Reduction of Toxicity, Mobility, or Volume through Treatment** – This criterion addresses the statutory preference for remedies that employ treatment as a principal element by assessing the relative performances of treatment technologies for reducing toxicity, mobility, or volume of the contaminated media. Specifically, the analysis should examine the magnitude, significance, and irreversibility of each estimated reduction. Reduction of toxicity, mobility, or volume through treatment was rated from very poor to very good.

Implementability Criterion

This criterion evaluates the technical and administrative feasibility of implementing an alternative and the availability of required services and materials. Implementability was rated from very poor to very good.

- **Technical Feasibility** – This criterion takes into account construction considerations, demonstrated performance, adaptability to environmental conditions, and timing. Technical feasibility was rated from very poor to very good.
- **Availability of Required Services and Materials** – This criterion evaluates whether staff, equipment services, disposal locations, etc., are available in the necessary time frames for construction and O&M activities. This criterion was combined with technical feasibility for this AAM.
- **Administrative Feasibility** – This criterion considers regulatory approval and scheduling constraints. Administrative feasibility was rated from very poor to very good.
- **Tribal, Supporting Agency, and Community Acceptance** – To allow for tribal and public input, this criterion will not be addressed and a preferred alternative will not be selected in this AAM. These criteria will be addressed in the final EE/CA after initial input from tribal and supporting agencies. Community acceptance will be addressed in the action memorandum after the public review and comment period on the final EE/CA.

Cost Criterion

The types of costs assessed include the following:

- Capital costs, including both direct and indirect costs
- Annual post-removal site control costs (termed O&M within this AAM for brevity)
- Net present value of capital and O&M costs

In accordance with USEPA (1993, 2000) guidance, engineering costs are estimates within plus 50 to minus 30 percent of the actual project cost (based on year 2021 dollars). Costs were rated from very poor to very good.

Cost Estimating Process

Cost estimates were prepared in accordance with USEPA (2000) guidelines using engineer's estimates, RSMeans 2021 cost estimating software (Gordian 2021), and vendor quotes. Farmington, New Mexico, was used as the reference city in the RSMeans software to estimate for labor, equipment, and supplies where applicable. In accordance with USEPA (1993, 2000) guidance, the engineering costs are estimates that are expected to be within plus 50 to minus 30 percent of the actual project cost (based on year 2021 dollars). Only the rolled up construction and capital costs, short-term O&M costs for site restoration, long-term O&M costs for burial cells and repositories, and net present values are presented for each alternative. Cost details and assumptions are presented in [Appendix E](#).

Cost estimating was conducted using a crew time and materials approach, which utilizes the time required for a crew to accomplish an activity based on a realistic production rate for site conditions. A unit cost approach utilizes RSMeans unit costs for construction based on cubic yard, linear feet, and square foot quantities, which would not be realistic because of the specific equipment needs and low production rates in remote, steep slope work areas. Other construction-related costs were identified and included in the cost approach, including mobilization and demobilization, contractor site overhead, travel and lodging, third-party oversight, Navajo Nation tax for on-Navajo Nation activities, and a 20 percent contingency. Non-construction-related costs required before and during construction activities were also identified and included in the cost approach, including design, planning, resource surveys, confirmation sampling, and reporting.

Contingency costs for construction are based on the extra time, equipment, and personnel required to safely work with radioactive materials; remote location of the site; differences in labor pool costs between RSMeans estimating software reference cities and the project area; and potential for changes in material and transportation costs. Changes in the cost elements are likely as commodity prices change and new information and data are collected during the engineering design and construction pre-bid and walk-through meetings.

The need for short- and long-term post-removal site control or O&M costs were identified, including the short-term need for site restoration for a period of 10 years to address any erosion and revegetation efforts and the long-term need for cap and cover maintenance for a period of 1,000 years for onsite consolidation and covering and on-Navajo Nation repository alternatives. Project duration (10 years versus 1,000 years) varies depending on the alternative being evaluated and will be addressed in the cost discussion for each alternative.

The net present value of each removal action alternative provides the basis for the cost comparison. The net present value represents the amount of money that, if invested in the initial year of the removal action at a given interest rate, would provide the funds required to make future payments to cover all O&M costs associated with the removal action over its planned life.

To assess the required funds to be set aside for implementing O&M activities in the future, this AAM uses a 3.5 percent discount rate, which is the 30-year rolling average of the annual discount rates for varying streams of payments as provided by the Office of Management and Budget (2020). The 3.5 percent discount rate would require more money to be set aside for future O&M costs than the historic average of 7 percent referenced in USEPA (1993) guidance.

4.3.1 Alternative 1: No Action

Under the no action alternative nothing would be done at the Brodie 1 Mine. The conditions that are currently found would remain unchanged.

4.3.1.1 Effectiveness

The effectiveness rating for Alternative 1 is **Very Poor** based on the following discussion.

Overall Protection of Public Health and the Environment (Rating: Not Protective) – The no action alternative would not achieve RAOs. This alternative would not minimize potential

exposure to or transport of COCs or COECs from the site or control radiation and physical hazards at the site. This alternative would not reduce risk to human health or the environment. Therefore, protection of human health and the environment would not be achieved under the no action alternative.

Compliance with ARARs (Rating: Not Applicable) – Under this alternative, there are no ARARs with which to comply per CERCLA § 121(d). ARARs provide specifications on the degree of cleanup and are, therefore, not pertinent if no cleanup occurs.

Short-Term Effectiveness (during Removal Action) (Rating: Very Good) – Alternative 1 has no action, so no short-term risks would exist for the community or workers from construction activities. However, threats to human and ecological receptors would persist in the short term. Because no construction activities would occur, no additional energy use, air pollution, water use, waste and materials management, and ecosystem protection requirements would be triggered. No additional traffic volume or potential accidents and fatalities associated with construction would occur.

Long-Term Effectiveness and Permanence (after Removal Action) (Rating: Very Poor) – No controls or long-term measures would be implemented to control COCs or COECs at the site under the no action alternative. Under this alternative, waste would continue to be accessible by humans and animals and subject to potential migration to uncontaminated or less contaminated areas. Risks at the site are currently unacceptable and would continue to be unacceptable under Alternative 1. Over time, the site risks may increase or decrease or remain the same as exposure to and migration of waste would not be controlled. Alternative 1 employs no onsite treatment, so no reductions in toxicity, mobility, or volume through active treatment would occur.

4.3.1.2 Implementability

The implementability rating for Alternative 1 is **Very Good** based on the following discussion.

Technical Feasibility and Availability of Services and Materials (Rating: Very Good) – Alternative 1 is readily implementable because no construction is involved. This alternative would not impact the ability to conduct removal or remedial actions in the future. No services or materials would be needed to implement Alternative 1.

Administrative Feasibility (Rating: Very Good) – Alternative 1 is administratively feasible as taking no action is always feasible.

4.3.1.3 Costs

Alternative 1 involves no removal activities and no legal or administrative activities. Therefore, Alternative 1 would incur no cost and would rate as **Very Good**.

4.3.2 Alternative 2: Consolidation and Capping

Alternative 2 involves excavation of mine waste and contaminated soil, removing waste from the existing burial cell under threat of headward cutting drainage, placing waste in a new burial cell, and capping of the burial cell.

4.3.2.1 Effectiveness

The effectiveness rating for Alternative 2 is rated **Good** based on the following discussion.

Overall Protection of Public Health and the Environment (Rating: Protective) – Under Alternative 2, overall protectiveness is considered good for achieving RAOs because soil and mine wastes that contain radionuclide and metal COCs and COECs would be capped within a burial cell. The potential for direct contact, ingestion, inhalation, and external irradiation of human and ecological receptors would be eliminated, and the risk to human and ecological receptors would be within acceptable levels with the proper maintenance of the cap. RAOs would be achieved in a short time frame because of waste isolation and containment. With proper cap maintenance, Alternative 2 would be protective of public health and the environment.

Compliance with ARARs (Rating: In Compliance) – Federal and tribal ARARs identified in [Table 13](#), [Table 14](#), and [Table 15](#) would be met for the site under Alternative 2.

Short-Term Effectiveness (during Removal Action) (Rating: Good) – The short-term impacts to the community, workers, and the environment under Alternative 2 are as described below.

- **Protection of the Community during Removal Action (Rating: Average)**– Dust control measures, such as water spraying, would be used during excavation and capping of the waste. However, some dust generation is unavoidable. Air monitors would be placed around the construction zone to measure potential risks to the community.

Increased truck traffic required to transport of equipment and construction materials to the mine and local waste excavation and consolidation activities at the onsite burial cell would have a short-term impact on traffic safety within the Sweetwater area and on air quality on dirt access roads. Because no waste is hauled off site, only small quantities of materials are hauled to the site, and the project duration is short, additional on-highway accidents and fatalities were not evaluated.

Over short-term O&M, an estimated 1.9 in 100 risk of an additional accident and 5.6 in 10,000 risk of an additional fatality for the 38,200 miles traveled during construction and 10 years of site restoration from on-highway traffic accidents are slightly elevated in comparison to Alternative 1 (no action) but remain low because of only 10 trips to the site for restoration inspections and repairs will be necessary.

- **Protection of Workers during Removal Action (Rating: Good)** – Onsite workers would require standard 40-hour Occupational Safety and Health Administration (OSHA) hazardous materials training and radiation awareness training and would be adequately protected by using appropriate personal protective equipment and following safe work practices and standards. Radiation exposure monitoring would be required. Short-term impacts to air quality in the surrounding environment may occur during excavation and placement of mine waste in the onsite burial cell. Dust suppression and monitoring would be required to ensure that workers are not exposed to or inhale radionuclides in particulates. Decontamination of workers and equipment would be required before exiting the site.

Short-term risks of physical injury would exist for site workers during construction, primarily related to operating equipment during access road construction, waste

excavation, site restoration, and burial cell construction. All workers will be required to wear personal dosimeters to ensure that exposure does not exceed OSHA limits.

- **Environmental Impacts** – Even with control measures, short-term environmental impacts could occur from waste excavation and construction of the burial cell. These environmental impacts may include sedimentation in the Tse Tah West Wash, residual soil and mud track-in and track-out effects, noise, disturbed vegetation, and dust generation. However, the threat to the environment is low because the mine waste could be cleaned up within 1 month. In addition, revegetation will expedite the return of native flora. The short-term threat posed by exposure to uranium and radionuclides would be minimal.
- **Greener Cleanups Analysis** – An analysis was completed that estimated the environmental footprint of the removal action for Alternative 2. The analysis determined the mass of different emissions generated by different construction activities, including greenhouse gases, nitrogen oxides, sulfur oxides, particulate matter, and listed air pollutants. For all categories, Alternative 2 was assessed as having a **medium** environmental footprint.
 - *Energy and Emissions* – Alternative 2 has a **small** energy and emissions footprint because of the onsite construction of a burial cell. However, over the long term, Alternative 2 has a **large** footprint because of the number of onsite visits required to inspect and manage the burial cell cap over 1,000 years (see long-term effectiveness). Use of local labor for inspections and reducing the number of inspections required per year would reduce the footprint. Use of electric, hybrid, ethanol, or compressed natural gas vehicles instead of conventional gasoline or diesel vehicles could reduce emissions.
 - *Water Resources* – Alternative 2 requires use of NTUA water or groundwater for waste compaction and dust control during excavation, backfill, grading, and on access roads. Alternative 2 has the lowest water use footprint because of onsite waste burial and the least amount of road dust control required. Overall, because of the relatively small construction area and volume of waste handled, Alternative 2 would have a **small** water resource footprint. Use of polymers could be considered to reduce water use for dust suppression.
 - *Materials Management* – Alternative 2 requires import of engineered riprap for stabilization of the onsite drainage, as well as import of gravel for onsite cap construction. Borrow soil for site restoration and capping will be from on site. Alternative 2 would have a **small** material management footprint because of the relatively small construction area and volume of waste handled. Reuse of local clean materials could be considered rather than importing borrow for fill.
 - *Land Management and Ecosystems Protection* – Alternative 2 has a **medium** footprint because site future land use would be limited by the burial cell footprint. Minimizing the burial cell aerial extent could be considered to reduce land use impacts. No negative ecosystem impacts were identified.
- **Time until RAOs Are Achieved** – Excavation, consolidation of mine waste in a new burial cell, and capping of the waste would meet preliminary RAOs in the short term. The

construction time required to achieve preliminary RAOs for Alternative 2 would be accomplished in about 1 month. Construction may be extended depending on schedule-limiting factors such as monsoon rains and snowfall.

Long-Term Effectiveness and Permanence (after Removal Action) (Rating: Average) –

Alternative 2 would safely and reliably contain all waste in an onsite burial cell with an ET cap, and RAOs would be achieved at all areas outside of the cap. Although the burial cell and cap are expected to be fully protective in the short and long term, the cap will require long-term inspection and maintenance.

Over the long term, additional accidents and fatalities could also result from site inspections and repairs during long-term O&M of the burial cell cap. Alternative 2 would have large energy and greenhouse gas footprints because of the high fuel consumption and emissions over the 1,000-year O&M duration. An estimated 2 in 10 risk of an additional accident and 6 in 1,000 risk of an additional fatality for the 405,000 miles traveled over 1,000 years from on-highway traffic accidents are possible in comparison to Alternative 1 (no action).

Land use controls would be necessary to limit access to and disturbance of the site and burial cell cap during restoration. A long-term surveillance plan (10 CFR § 40.28) would be implemented after burial cell construction to ensure cap integrity. For the areas at the site where all waste has been removed, short-term monitoring and repair of revegetation and erosion controls would also be required for up to 10 years.

Alternative 2 would not require replacement of components because their lifespan is indefinite under an inspection and maintenance regime as described above. Force majeure events, such as earthquakes, climate change, or large floods, could impact the remedy or waste left in place, but design criteria for the remedy would take these into account to the extent practicable.

Finally, the uncertainties of disposing of waste on site under Alternative 2 are considered low because of the stable nature of the waste, design of the burial cell and ET cap, use of conventional materials and methods, and long track record of ET caps as an accepted remedy.

Alternative 2 employs no onsite treatment, so no reductions in toxicity, mobility, or volume through active treatment would occur.

4.3.2.2 Implementability

The implementability rating for Alternative 2 is **Very Good** based on the following discussion.

Technical Feasibility and Availability of Services and Materials (Rating: Very Good) –

Alternative 2 consists of simple earthwork and material hauling. Alternative 2 requires a contractor experienced in the excavation of mine waste, ET cap construction, drainage channel reconstruction, biodegradable matting and wattles, and stormwater diversion berms and ditches, hazardous substances, and traffic, dust, and stormwater management. The equipment required for the work is readily available and consists of scrapers, loaders, dozers, crushing/screening plant for borrow materials, and articulated haul trucks.

Construction and environmental monitoring equipment and services are all readily available. Labor would be available both on the Navajo Nation and in the regional market. A sufficient volume of water for dust suppression may be obtained through construction of a water well at Block K Mine or connection with a nearby NTUA water pipeline.

Sources of borrow material are sufficient to meet the needs for fill, topsoil, and gravel for capping options under all potential cap designs and for restoration after excavation. Riprap will need to be imported from Durango, Colorado, to meet engineering specifications for armoring drainage channels.

Alternative 2 would be completed as a single phase, and no future removal actions are anticipated. The expertise and equipment for long-term monitoring and maintenance of the burial cell cap, erosional features and controls, and revegetation are and will be available. Run-on water control berms, drainage ditches, and sediment detention basins around the burial cell cap would be repaired as necessary. Permanent range fencing and permanent warning signs would also be checked and repaired or replaced as necessary.

Administrative Feasibility (Rating: Very Good) – Implementation of Alternative 2 would require coordination between USEPA, NNEPA, and NAMLRD to address federal and tribal ARARs, but federal permits for onsite actions under CERCLA are not required. General construction permits and environmental reviews may be required from the Navajo Nation. Finally, negotiations with the Navajo Nation or other landowners with potential offsite soil borrow sources would need to be conducted and agreements crafted.

The entity responsible for the long-term surveillance plan would maintain various plans and conduct periodic inspections and reviews, including:

- A stormwater pollution prevention plan (SWPPP) overseen by NNEPA (to verify that restoration is protective of surface water quality)
- A long-term surveillance plan implemented after burial cell cap construction and overseen by NNEPA and USEPA

Land use controls for waste placed in the burial cell would require coordination with NNEPA, the Navajo Nation Lands Department, and the Sweetwater Chapter because deed restrictions are not possible on the Navajo Nation.

4.3.2.3 Costs

Overall, Alternative 2 has the highest cost among all alternatives because of both short-term (10-year) site restoration O&M costs and long-term (1,000-year) burial cell cap O&M costs. A cost sharing option with other sites is not possible. The overall effectiveness of Alternative 2 is rated **Good** (after the **Good** rating for short-term effectiveness is combined with the **Average** rating for long-term effectiveness and permanence). The high costs compared with the **Good** overall effectiveness rating means that Alternative 2 is not as cost effective as an alternative with multi-site disposal in a single repository, and the cost rating is **Poor**.

The total net present value cost for Alternative 2 is estimated at \$3,099,496 using a 3.5 percent discount rate. The net present value cost includes total capital costs (\$2,240,257), annual O&M costs (\$24,646) for site restoration inspection and maintenance costs over 10 years, and annual O&M costs (\$22,899) for repository inspection and maintenance costs over 1,000 years.

A breakdown of the major cost categories associated with implementing Alternative 2 is presented below. Detailed cost estimates are provided in [Appendix E](#) and [Table E-2](#).

Cost Component	Brodie 1 Mine
Excavated Surface Area (ft ²)	9,702
Excavated Volume (yd ³)	1,310
Capital Costs	
Site Access	\$84,931
Waste Excavation	\$11,418
Site Restoration	\$141,648
Burial Cell Construction	\$700,601
Other Construction	\$0
Subtotal Construction Costs	\$938,599
Non-Construction	\$1,301,658
Total Capital Costs	\$2,240,257
O&M Costs	
Annual Site Restoration (10 years)	\$24,646
Annual Access Road Maintenance (1,000 years)	\$13,140
Annual Burial Cell Cap Maintenance (1,000 years)	\$9,759
Total Annual O&M Costs	\$47,545
NPV Costs	
10-Year Site Restoration	\$204,983
1,000 Year Access Road Maintenance	\$375,423
1,000 Year Burial Cell Maintenance	\$278,834
Total NPV Costs	\$3,099,496

Notes:

ft² Square feet
 NPV Net present value
 O&M Operation and maintenance
 yd³ Cubic yard

4.3.3 Alternative 3: Excavation, Transport, and Disposal in On-Navajo Nation Regional Repository

Alternative 3 involves excavation of mine waste and contaminated soil, transport, and disposal in a regional repository near the Block K mine.

4.3.3.1 Effectiveness

The effectiveness rating for Alternative 3 is **Average** based on the following discussion.

Overall Protection of Public Health and the Environment (Rating: Protective) – Under Alternative 3, overall protectiveness is considered good for achieving RAOs because soil and mine wastes that contain radionuclide and metal COCs and COECs would be capped within a regional repository. The potential for direct contact, ingestion, inhalation, and external irradiation

by human and ecological receptors would be eliminated, and the risk to human and ecological receptors would be within acceptable levels with the proper maintenance of the repository cap. RAOs would be achieved in a short time frame because of waste isolation and containment. With proper cap maintenance, Alternative 3 would be protective of public health and the environment.

Compliance with ARARs (Rating: In Compliance) – Federal and tribal ARARs identified in [Table 13](#), [Table 14](#), and [Table 15](#) would be met for the site under Alternative 3.

Short-Term Effectiveness (during Removal Action) (Rating: Average) – The short-term impacts to the community, workers, and environment under Alternative 3 are as described below.

- **Protection of the Community during Removal Action (Rating Average)** – Dust control measures, such as water spraying, would be used during excavation, waste hauling, regional repository construction, waste compaction, and capping of the waste. However, some dust generation is unavoidable. Air monitors would be placed around the construction zone at the site and repository to measure potential risks to the community.

Increased truck traffic required to transport equipment and construction materials to the mine and waste excavation, waste hauling, and consolidation activities at the regional repository would have a short-term impact on traffic safety within the Sweetwater and Teec Nos Pos Chapters and on air quality on dirt access roads.

Over the short term, an estimated 1.5 in 100 risk of an additional accident and 4.6 in 10,000 risk of an additional fatality for the 31,300 miles traveled during construction and 10 years of site restoration from on-highway traffic accidents are slightly elevated in comparison to Alternative 2 (onsite burial cell) but remain low because of the short on-highway travel distance between the Brodie 1 Mine and the regional repository.

- **Protection of Workers during Removal Action (Rating: Average)** – Onsite workers would require standard 40-hour OSHA hazardous materials training and radiation awareness training and would be adequately protected by using appropriate personal protective equipment and following safe work practices and standards. Radiation exposure monitoring would be required. Short-term impacts to air quality in the surrounding environment may occur during excavation, repository construction, and placement of mine waste in the regional repository. Dust suppression and monitoring would be required to ensure that workers are not exposed to or inhale radionuclides in particulates. Decontamination of workers and equipment would be required before exiting the site.

Short-term risks of physical injury would exist for site workers during construction, primarily related to operating equipment during access road construction, waste excavation, site restoration, and repository construction. All workers will be required to wear personal dosimeters to ensure that exposure does not exceed OSHA limits.

- **Environmental Impacts** – Even with control measures, short-term environmental impacts could occur. These environmental impacts may include sedimentation in the Tse Tah West Wash, residual track-in and track-out effects of soil and mud, noise, disturbed vegetation, and dust generation. However, the threat to the environment is low because the mine waste could be cleaned up within 2 months. In addition, revegetation will

expedite the return of native flora. The short-term threat posed by exposure to uranium and radionuclides would be minimal.

- **Greener Cleanups Analysis** –An analysis was completed that estimated the environmental footprint of the removal action for Alternative 3. The analysis determined the mass of different emissions generated by different construction activities, including greenhouse gases, nitrogen oxides, sulfur oxides, particulate matter, and listed air pollutants. For all categories, Alternative 3 was assessed as having a **medium** environmental footprint.
 - *Energy and Emissions* – Alternative 3 has a **small** energy and emissions footprint because of the consolidation of waste from multiple sites in a regional repository. However, over the long term, Alternative 3 would have a **large** footprint because of the number of onsite visits required to inspect and manage the repository cap over 1,000 years (see long-term effectiveness). Use of local labor for inspections and reducing the number of inspections required per year would reduce the footprint. Use of electric, hybrid, ethanol, or compressed natural gas vehicles instead of conventional gasoline or diesel vehicles could reduce emissions.
 - *Water Resources* – Alternative 3 requires use of NTUA water or groundwater for waste compaction and dust control during excavation, loading, backfill, grading, and on haul roads. Overall, because of the relatively small construction area and volume of waste handled, Alternative 3 would have a **small** water resource footprint. Use of polymers could be considered to reduce water use for dust suppression.
 - *Materials Management* – Alternative 3 requires hauling waste from the Brodie 1 Mine and importing gravel for regional repository construction. Borrow soil for site restoration and capping will be from on site. Alternative 3 would have a **small** material management footprint because of the relatively small construction area and volume of waste handled. Reuse of local clean materials could be considered rather than importing borrow for fill.
 - *Land Management and Ecosystems Protection* – Alternative 3 has a **medium** footprint because site future land use would be limited by repository footprint. Minimizing the repository aerial extent could be considered to reduce land use impacts. Use of geomorphic grading for repository closure would minimize visual impacts. No negative ecosystem impacts were identified.
- **Time until RAOs Are Achieved** – Excavation, consolidation, and containment of waste in a new regional repository would meet preliminary RAOs in the short term. The construction time required to achieve preliminary RAOs for Alternative 3 would be accomplished in about 2 months at the Brodie 1 Mine and regional repository site. Construction may be extended depending on schedule-limiting factors such as monsoon rains and snowfall.

Long-Term Effectiveness and Permanence (after Removal Action) (Rating: Good) –

Alternative 3 would safely and reliably contain all waste in a new regional repository with an ET cap, and RAOs would be achieved at all areas at the Brodie 1 Mine. Although the regional

repository and ET cap are expected to be fully protective in the short and long term, the cap will require long-term inspection and maintenance.

Over the long term, additional accidents and fatalities could also result from site inspections and repairs during long-term O&M of the regional repository cap. Alternative 3 would have large energy and greenhouse gas footprints because of the high fuel consumption and emissions over the 1,000-year O&M duration. An estimated 2 in 10 risk of an additional accident and 6 in 1,000 risk of an additional fatality for the 405,000 miles traveled over 1,000 years from on-highway traffic accidents are possible in comparison to Alternative 2 (onsite burial cell). There is no difference in long-term additional accidents and fatalities for Alternatives 2 and 3 as the travel distance is essentially the same.

Land use controls would be necessary to limit access to and disturbance of the site and the regional repository during restoration. A long-term surveillance plan (10 CFR § 40.28) would be implemented after repository construction to ensure cap integrity. For the areas at the site where all waste has been removed, short-term monitoring and repair of revegetation and erosion controls would also be required for up to 10 years.

Alternative 3 would not require replacement of components because their lifespan is indefinite under an inspection and maintenance regime as described above. Force majeure events, such as earthquakes, climate change, or large floods, could impact the remedy or waste left in place, but design criteria for the remedy would take these into account to the extent practicable.

Finally, the uncertainties of disposing of waste in a regional repository under Alternative 3 are considered low because of the stable nature of the waste, design of the repository and ET cap, use of conventional materials and methods, and long track record of repositories as an accepted remedy.

Alternative 3 employs no onsite treatment, so no reductions in toxicity, mobility, or volume through active treatment would occur.

4.3.3.2 Implementability

The implementability rating for Alternative 3 is **Good**, based on the following discussions.

Technical Feasibility and Availability of Services and Materials (Rating: Very Good) – Alternative 3 consists mainly of simple earthwork and material hauling. Alternative 3 requires a contractor experienced in the excavation of mine waste, repository and ET cap construction, drainage channel reconstruction, biodegradable matting and wattles, and stormwater diversion berms and ditches, hazardous substances, and traffic, dust, and stormwater management. The equipment required for the work is readily available and consists of scrapers, loaders, dozers, crushing/screening plant for borrow materials, and articulated haul trucks. The transport of waste to the regional repository near Block K will require a 30-minute cycle time for trucks.

Construction and environmental monitoring equipment and services are all readily available. Labor would be available both on the Navajo Nation and in the regional market. A sufficient volume of water for dust suppression may be obtained through construction of a water well at the repository or connection with a nearby NTUA water pipeline.

Sources of borrow material are enough to meet the needs for fill, topsoil, and gravel for capping options under all potential cap designs and for restoration after excavation. Riprap will need to be imported from Durango, Colorado, to meet engineering specifications for armoring drainage channels.

Alternative 3 would be completed as a single phase, and no future removal actions are anticipated. Long-term maintenance of the repository cap would be required. The expertise and equipment for long-term monitoring and maintenance of the repository cap, erosional features and controls, and revegetation are and will be available. Run-on water control berms, drainage ditches, and sediment detention basins at the repository would be repaired as necessary. Permanent range fencing and warning signs around the repository would also be checked and repaired or replaced as necessary.

Administrative Feasibility (Rating: Average) – Implementation of Alternative 3 would require coordination between USEPA, NNEPA, and NAMLRD to address federal and tribal ARARs, but federal permits for onsite actions under CERCLA, such as the proposed regional repository location in a mining disturbed area (drilled and explored extensively) and within a mine lease boundary, are not required. General construction permits and environmental reviews may be required from the Navajo Nation. Finally, negotiations with the Navajo Nation or other landowners with potential offsite soil borrow sources and repository areas would need to be conducted and agreements crafted.

The entity responsible for the long-term surveillance plan would maintain various plans and conduct periodic inspections and reviews, including:

- A SWPPP overseen by NNEPA (to verify that restoration is protective of surface water quality)
- A long-term surveillance plan implemented after repository cap construction and overseen by NNEPA and USEPA

Land use controls for waste placed in the repository would require coordination with NNEPA, the Navajo Nation Lands Department, and the Sweetwater Chapter because deed restrictions are not possible on the Navajo Nation.

4.3.3.3 Costs

Overall, Alternative 3 has one of lower costs of all the alternatives because of local hauling and disposal in a regional repository even after both short-term (10-year) site restoration O&M costs and long-term (1,000-year) regional repository O&M costs are considered. Cost savings are also realized by sharing repository costs with other mine sites. The overall effectiveness of Alternative 3 is rated **Average** (after the **Average** rating for short-term effectiveness is combined with the **Good** rating for long-term effectiveness and permanence). The low costs compared with the **Average** overall effectiveness rating means that Alternative 3 is cost effective, and the cost rating is **Average**.

The total net present value cost for Alternative 3 is estimated at \$2,703,132 using a 3.5 percent discount rate. The net present value cost includes total capital costs (\$2,030,876), annual O&M

costs (\$24,646) for site restoration inspection and maintenance costs over 10 years, and annual O&M costs (\$16,349) for repository inspection and maintenance costs over 1,000 years.

A breakdown of the major cost categories associated with implementing Alternative 3 is presented below. Detailed cost estimates are provided in [Appendix E](#) and [Table E-3](#).

Cost Component	Brodie 1 Mine
Excavated Surface Area (ft ²)	9,702
Excavated Volume (yd ³)	1,310
Capital Costs	
Site Access	\$90,795
Waste Excavation and Hauling	\$57,090
Site Restoration	\$141,648
Haul Road Restoration	\$121,674
Repository Construction (shared)	\$240,287
Other Construction	\$0
Subtotal Construction Costs	\$651,494
Non-Construction	\$1,379,381
Total Capital Costs	\$2,030,875
O&M Costs	
Annual Site Restoration (10 years)	\$24,646
Annual Access Road Maintenance (1,000 years)	\$13,140
Annual Burial Cell Cap Maintenance (1,000 years)	\$3,209
Total Annual O&M Costs	\$40,995
NPV Costs	
10-Year Site Restoration	\$204,983
1,000 Year Access Road Maintenance	\$375,423
1,000 Year Burial Cell Maintenance	\$91,850
Total NPV Costs	\$2,703,132

Notes:

ft² Square feet
 NPV Net present value
 O&M Operation and maintenance
 yd³ Cubic yard

4.3.4 Alternative 4: Excavation, Off-Navajo Nation Transport, and Disposal at White Mesa Mill

Alternative 4 involves excavation of mine waste and contaminated soil, transport, and milling and disposal at the White Mesa Mill.

4.3.4.1 Effectiveness

The effectiveness rating for Alternative 4 is **Good** based on the following discussion.

Overall Protection of Public Health and the Environment (Rating: Protective) – Under Alternative 4, overall protectiveness is considered good for achieving RAOs because soil and mine wastes that contain radionuclide and metal COCs and COECs would be hauled off site, milled, and uranium recovered before waste is placed in an tailings disposal facility. Therefore, potential direct contact, ingestion, inhalation, and external irradiation by human and ecological

receptors would be eliminated. RAOs would be achieved in a short time frame because waste would be removed from the Brodie 1 Mine site and contained in an offsite tailings disposal facility. Alternative 4 would be protective of public health and the environment.

Compliance with ARARs (Rating: In Compliance) – Alternative 4 will meet ARARs identified in Table 13, Table 14, and Table 15. Most of the components of Alternative 4, including the ultimate disposition of the waste, will occur offsite. ARARs do not apply offsite. Instead, offsite actions must comply with independently applicable requirements (not relevant and appropriate). Independently applicable requirements cannot be waived and all components, both substantive and procedural must be complied with.

Short-Term Effectiveness (during Removal Action) (Rating: Poor) – The short-term impacts to the community, workers, and environment under Alternative 4 are as described below.

- **Protection of the Community during Removal Action (Rating: Average)** – Dust control measures, such as water spraying, would be used during waste excavation, loading, and hauling to Indian Route 35 for offsite transport. However, some dust generation is unavoidable. Air monitors would be placed around the construction zone to measure potential risks to the community.

Increased truck traffic required to transport equipment and construction materials to the mine site and local waste excavation would have a short-term impact on traffic safety within the Sweetwater Chapter and air quality on dirt access roads. Hauling waste from the mine site to the off-Navajo Nation White Mesa Mill located south of Blanding, Utah, would lead to increased traffic on the Brodie 1 Mine access road, Indian Route 35, and along the route to the mill facility for up to 1 month.

Over the short term, an estimated 1.8 in 100 risk of an additional accident and 5.5 in 10,000 risk of an additional fatality for the 37,400 miles traveled during construction and 10 years of site restoration from on-highway traffic accidents are slightly elevated in comparison to Alternatives 2 and 3 (onsite burial cell and regional repository) because of the 63 mile haul distance between the Brodie 1 Mine and the White Mesa Mill.

- **Protection of Workers during Removal Action (Rating: Poor)** – Onsite workers would require standard 40-hour OSHA hazardous materials training and radiation awareness training and would be adequately protected by using appropriate personal protective equipment and following safe work practices and standards. Radiation exposure monitoring would be required. Short-term impacts to air quality in the surrounding environment may occur during excavation and loading of waste for offsite transport. Dust suppression and monitoring would be required to ensure that workers are not exposed to or inhale radionuclides in particulates. Decontamination of workers and equipment would be required before exiting the site.

Short-term risks of physical injury would exist for site workers during construction, primarily related to operating equipment during waste excavation, site restoration, and access road construction. All workers will be required to wear personal dosimeters to ensure that exposure does not exceed OSHA limits. The risk to truck drivers would be greater than that for Alternative 3 because of the increase in time and miles required for transport.

- **Environmental Impacts** – Even with control measures, short-term environmental impacts could occur. These environmental impacts may include sedimentation in the Tse Tah West Wash, residual track-in and track-out effects of soil and mud, noise, disturbed vegetation, and dust generation. However, the threat to the environment is low because the mine waste could be cleaned up within 1 month. In addition, revegetation will expedite the return of native flora. The short-term threat posed by exposure to uranium and radionuclides would be minimal.
- **Greener Cleanups Analysis** – An analysis was completed that estimated the environmental footprint of the removal action for Alternative 4. The analysis determined the mass of different emissions generated by different construction activities, including greenhouse gases, nitrogen oxides, sulfur oxides, particulate matter, and listed air pollutants. For all categories, Alternative 4 was assessed as having a **small** environmental footprint.
 - *Energy and Emissions* – Alternative 4 has a **small** footprint because of the relatively short (10-year) site inspection visits for site restoration even after the offsite haul distance is considered. Use of local labor for inspections and reducing the number of inspections required per year would reduce the footprint. Use of electric, hybrid, ethanol, or compressed natural gas vehicles instead of conventional gasoline or diesel vehicles could reduce emissions.
 - *Water Resources* – Alternative 4 does not involve onsite disposal and would not require water for waste compaction. Alternative 4 requires water for dust control during excavation, loading, backfill, grading and on haul roads and would require use of NTUA water or groundwater. Overall, because of the relatively small construction area and volume of waste handled, Alternative 4 would generally have a **small** water resource footprint. Use of polymers could be considered to reduce water use for dust suppression on haul roads.
 - *Materials Management* – Alternative 4 requires import of engineered riprap for construction of the onsite drainage. Borrow soil for site restoration will be from on site. Waste would be hauled off site. Overall, because of the relatively small construction area, Alternative 4 would have a **small** materials management footprint. Reuse of local clean materials could be considered rather than importing borrow for fill. Identification of an alternate disposal facility closer to the site could reduce fuel consumption and emissions.
 - *Land Management and Ecosystems Protection* – Alternative 4 has a **small** land management and ecosystems protection footprint as all the waste will be hauled off site. No negative ecosystem impacts were identified.
- **Time until RAOs Are Achieved** – Excavation, hauling off Navajo Nation, milling, and disposal of milled tailings in a tailings disposal facility would meet preliminary RAOs in the short term. The construction time required to achieve preliminary RAOs for Alternative 4 would be about 1 month. Construction may be extended depending on schedule-limiting factors such as haul truck availability, monsoon rains, and snowfall.

Long-Term Effectiveness and Permanence (after Removal Action) (Rating: Very Good) – Alternative 4 would relocate and safely mill and dispose of all waste in a licensed uranium milling facility, and RAOs would be achieved at all areas on the site. No sources of mining-related residual risk would remain at the Brodie 1 Mine.

No long-term O&M is required for Alternative 4 because no waste will remain on site. Therefore, Alternative 4 has a substantial advantage over on-Navajo Nation actions, which would require up to 1,000 years of burial cell or repository cap inspections and maintenance.

Land use controls would be necessary to limit access to and disturbance of the site during restoration. Short-term monitoring of revegetation efforts and erosion controls would also be required. Replacement of components over the long term would not be required because no waste would remain on site. Inspection and maintenance of restoration features would only be required for a period up to 10 years.

Finally, the uncertainties of disposing of waste off site under Alternative 4 are considered low because of the use of conventional materials and methods and the long track record of uranium milling facilities as an accepted remedy.

Alternative 4 employs no onsite treatment, so no reductions in toxicity, mobility, or volume through active treatment would occur.

4.3.4.2 Implementability

The implementability rating for Alternative 4 is **Good** based on the following discussion.

Technical Feasibility and Availability of Services and Materials (Rating: Good) – Alternative 4 consists mainly of simple earthwork and material hauling. Alternative 4 requires a contractor experienced in the excavation of mine waste, coordinating long distance transport of waste, drainage channel reconstruction, biodegradable matting and wattles, and stormwater diversion berms and ditches, hazardous substances, and traffic, dust, and stormwater management. The equipment required for the work is readily available and consists of scrapers, loaders, dozers, crushing/screening plant for borrow materials, and on-highway haul trucks. The transport of waste to the White Mesa Mill will increase the cycle time for trucks to approximately 4 hours, resulting in the need for more trucks or increased construction time.

Construction and environmental monitoring equipment and services are all readily available. Labor would be available both on the Navajo Nation and in the regional market. Availability of on-highway haul trucks may be a limiting factor and increase project duration. Access to a sufficient volume of water for dust suppression is necessary, which would be obtained through construction of an onsite water well or connection with a nearby NTUA water pipeline.

Sources of borrow material are enough to meet the needs for fill and topsoil for restoration after excavation. Riprap will need to be imported from Durango, Colorado, to meet engineering specifications for armoring drainage channels.

Alternative 4 would be completed as a single phase, and no future removal actions are anticipated. Long-term monitoring and maintenance would not be required; however, short-term

maintenance of erosional controls and revegetation efforts would be required. Run-on water control berms, drainage ditches, and sediment detention basins would be repaired as necessary. Temporary range fencing around the restored site would also be checked and repaired as necessary.

The White Mesa Mill facility is currently in compliance with its State of Utah operating permit and with the CERCLA Off-Site Rule. Because all waste would be disposed of off site, exclusive reliance on the operational capacity of the White Mesa Mill facility brings uncertainty to the availability of services at the time of the removal action. No other mill facilities are in operation in the region; therefore, selection of an alternate method of disposal could be required in the action memorandum if necessary.

Administrative Feasibility (Rating: Good) – Implementation of Alternative 4 would require coordination between USEPA, NNEPA, and NAMLRD to address federal and tribal ARARs, but federal permits for onsite actions under CERCLA are not required. General construction permits and environmental reviews may be required from the Navajo Nation. Finally, negotiations with the Navajo Nation or other landowners with potential offsite soil borrow sources would need to be conducted and agreements crafted.

Offsite processing or disposal of materials from a CERCLA site must comply with the CERCLA Off-Site Rule. The White Mesa Mill currently has approval under the Off-Site Rule and would need to maintain such approval.

The entity responsible for the short-term surveillance of site restoration efforts would maintain various plans and conduct periodic inspections and reviews, including a SWPPP overseen by NNEPA (to verify that restoration is protective of surface water quality).

4.3.4.3 Costs

Overall, Alternative 4 has the lowest costs of all the alternatives because of the short-term (10-year) site restoration O&M costs even after trucking costs and White Mesa Mill processing and disposal fees are considered. The overall effectiveness of Alternative 4 is rated **Good** (after the **Poor** rating for short-term effectiveness is combined with the **Very Good** rating for long-term effectiveness and permanence). The low costs compared with the **Good** overall effectiveness rating means that Alternative 4 is cost effective, and the cost rating is **Good**.

The total net present value cost for Alternative 4 is estimated at \$2,263,058 using a 3.5 percent discount rate. The net present value cost includes total capital costs (\$2,058,075), and annual O&M costs (\$24,646) for site restoration inspection and maintenance costs over 10 years.

A breakdown of the major cost categories associated with implementing Alternative 4 is presented below. Detailed cost estimates are provided in [Appendix E](#) and [Table E-4](#).

Cost Component	Brodie 1 Mine
Excavated Surface Area (ft ²)	9,702
Excavated Volume (yd ³)	1,310
Capital Costs	
Site Access	\$84,931
Waste Excavation and Loading	\$32,442
Site Restoration	\$141,648
Haul Road Restoration	\$121,674
Waste Hauling to White Mesa Mill	\$37,139
Disposal at White Mesa Mill	\$132,638
Subtotal Construction Costs	\$550,472
Non-Construction	\$1,507,603
Total Capital Costs	\$2,058,075
O&M Costs	
Annual Site Restoration (10 years)	\$24,646
Total Annual O&M Costs	\$24,646
NPV Costs	
10-Year Site Restoration	\$204,983
Total NPV Costs	\$2,263,058

Notes:

ft² Square feet

NPV Net present value

O&M Operation and maintenance

yd³ Cubic yard

4.3.5 Alternative 5: Excavation, Off-Navajo Nation Transport, and Disposal at Hazardous Waste or Low-Level Radioactive Waste Facility

Alternative 5 involves excavation of mine waste and contaminated soil, transport, and disposal in a hazardous waste or LLRW facility.

4.3.5.1 Effectiveness

The effectiveness rating for Alternative 5 is **Average** based on the following discussion.

Overall Protection of Public Health and the Environment (Rating: Protective) – Under Alternative 5, overall protectiveness is considered good for achieving RAOs because soil and mine wastes that contain radionuclide and metal COCs and COECs would be hauled off site and disposed at an off-Navajo Nation hazardous waste disposal facility. Therefore, potential direct contact, ingestion, inhalation, and external irradiation by human and ecological receptors would essentially be eliminated. RAOs would be achieved in a short time frame because waste would be removed from the Brodie 1 Mine site and contained in an offsite disposal facility. Alternative 5 would be protective of public health and the environment.

Compliance with ARARs (Rating: In Compliance) – Alternative 5 will meet ARARs identified in [Table 13](#), [Table 14](#), and [Table 15](#). Most of the components of Alternative 5, including the ultimate disposition of the waste, will occur offsite. ARARs do not apply offsite. Instead, offsite actions must comply with independently applicable requirements (not

relevant and appropriate). Independently applicable requirements cannot be waived and all components, both substantive and procedural must be complied with.

Short-Term Effectiveness (during Removal Action) (Rating: Very Poor) – The short-term impacts to the community, workers, and environment under Alternative 5 are as described below.

- **Protection of the Community during Removal Action (Rating: Poor)** – Dust control measures, such as water spraying, would be used during waste excavation, loading, and hauling to Indian Route 35 for offsite transport. However, some dust generation is unavoidable. Air monitors would be placed around the construction zone to measure potential risks to the community. Trucks hauling equipment and supplies would also add traffic and noise.

Increased truck traffic required to transport equipment and construction materials to the mine site and local waste excavation would have a short-term impact on traffic safety within the Sweetwater Chapter and air quality on dirt access roads. Hauling waste from the mine site to the off-Navajo Nation Clean Harbors RCRA Subtitle C hazardous waste disposal facility located near Deer Trail, Colorado, would lead to increased traffic on the Brodie 1 Mine access road, Indian Route 35, and along the route to the disposal facility for 2 months.

Over the short term, an estimated 6.6 in 100 risk of an additional accident and 2 in 1,000 risk of an additional fatality for the 135,800 miles traveled during construction and 10 years of site restoration from on-highway traffic accidents are elevated by a factor of 4 in comparison to Alternatives 2 and 3 (burial cell and regional repository) because of the 565 mile haul distance between the Brodie 1 Mine and the Clean Harbors RCRA Subtitle C hazardous waste disposal facility.

- **Protection of Workers during Removal Action (Rating: Very Poor)**– Onsite workers would require standard 40-hour OSHA hazardous materials training and radiation awareness training and would be adequately protected by using appropriate personal protective equipment and following safe work practices and standards. Radiation exposure monitoring would be required. Short-term impacts to air quality in the surrounding environment may occur during excavation and loading of waste for offsite transport. Dust suppression and monitoring would be required to ensure that workers are not exposed to or inhale radionuclides in particulates. Decontamination of workers and equipment would be required before exiting the site.

Short-term risks of physical injury would exist for site workers during construction, primarily related to operating equipment during waste excavation, site restoration, and access road construction. All workers will be required to wear personal dosimeters to ensure that exposure does not exceed OSHA limits. The risk to truck drivers would be greater than that for Alternatives 3 and 4 because of the increase in time and miles required for transport.

- **Environmental Impacts** – Even with control measures, short-term environmental impacts could occur. These environmental impacts may include sedimentation in the Tse Tah West Wash, residual track-in and track-out effects of soil and mud, noise, disturbed vegetation, and dust generation. However, the threat to the environment is low because the mine waste could be cleaned up within 2 months. In addition, revegetation will

expedite the return of native flora. The short-term threat posed by exposure to uranium and radionuclides would be minimal.

- **Greener Cleanups Analysis** – An analysis was completed that estimated the environmental footprint of the removal action for Alternative 5. The analysis determined the mass of different emissions generated by different construction activities, including greenhouse gases, nitrogen oxides, sulfur oxides, particulate matter, and listed air pollutants. For all categories, Alternative 5 was assessed as having a **medium** environmental footprint.
 - *Energy and Emissions* – Alternative 5 has a **large** footprint because of the relatively short (10-year) site inspection visits for site restoration even after the offsite haul distances are considered. Use of local labor for inspections and reducing the number of inspections required per year would reduce the footprint. Use of electric, hybrid, ethanol, or compressed natural gas vehicles instead of conventional gasoline or diesel vehicles could reduce emissions.
 - *Water Resources* – Alternative 5 does not involve onsite disposal and would not require water for waste compaction. Alternative 5 requires water for dust control during excavation, loading, backfill, grading, and on haul roads and would require use of NTUA water or groundwater. Overall, because of the relatively small construction area and volume of waste handled, Alternative 5 would generally have a **small** water resource footprint. Use of polymers could be considered to reduce water use for dust suppression on haul roads.
 - *Materials Management* – Alternative 5 requires import of engineered riprap for construction of the onsite drainage. Borrow soil for site restoration will be from on site. Waste would be hauled off site. Overall, because of the relatively small construction area, Alternative 5 would have a **small** materials management footprint. Reuse of local clean materials could be considered rather than importing borrow for fill. Identification of an alternate disposal facility closer to the site could reduce fuel consumption and emissions.
 - *Land Management and Ecosystems Protection* – Alternative 5 has a **small** land management and ecosystems protection footprint as all the waste will be hauled off site. No negative ecosystem impacts were identified.
- **Time until RAOs Are Achieved** – Excavation, hauling off-Navajo Nation, and disposal of waste at the Clean Harbors RCRA Subtitle C hazardous waste disposal facility would meet preliminary RAOs in the short term. The construction time required to achieve preliminary RAOs for Alternative 5 would be about 2 months due to the 3 day truck cycle time. Construction may be extended depending on schedule-limiting factors such as truck availability, monsoon rains, and snowfall.

Long-Term Effectiveness and Permanence (after Removal Action) (Rating: Very Good) – Alternative 5 would relocate and safely dispose of all waste in a hazardous waste disposal facility, and RAOs would be achieved at all areas on site. No sources of mining-related residual risk would remain at the Brodie 1 Mine.

No long-term O&M is required for Alternative 5 because no waste will remain on site. Therefore, Alternative 5 has a substantial advantage over on-Navajo Nation actions which would require up to 1,000 years of burial cell or repository cap inspections and maintenance.

Land use controls would be necessary to limit access to and disturbance of the site during restoration. Short-term monitoring of revegetation efforts and erosion controls would also be required. Replacement of components over the long term would not be required because no waste would remain on site. Inspection and maintenance of restoration features would only be required for a period up to 10 years.

Finally, the uncertainties of disposing of waste off site under Alternative 5 are considered low because of the use of conventional materials and methods and the long track record of hazardous waste disposal facilities as an accepted remedy.

Alternative 5 employs no treatment, so no reductions in toxicity, mobility, or volume through treatment would occur.

4.3.5.2 Implementability

The implementability rating for Alternative 5 is **Very Good** based on the following discussion.

Technical Feasibility and Availability of Services and Materials (Rating: Very Good) – Alternative 5 consists mainly of simple earthwork and material hauling. Alternative 5 requires a contractor experienced in the excavation of mine waste, coordinating long distance transport of waste, drainage channel reconstruction, biodegradable matting and wattles, and stormwater diversion berms and ditches, hazardous substances, and traffic, dust, and stormwater management. The equipment required for the work is readily available and consists of scrapers, loaders, dozers, crushing/ screening plant for borrow materials, and on-highway haul trucks. The transport of waste to the hazardous waste landfill will increase the cycle time for trucks to approximately 3 days, resulting in the need for more trucks or increased construction time.

Construction and environmental monitoring equipment and services are all readily available. Labor would be available both on the Navajo Nation and in the regional market. Availability of on-highway haul trucks may be a limiting factor and increase project duration. Access to a sufficient volume of water for dust suppression is necessary, which would be obtained through construction of an onsite water well or connection with a nearby NTUA water pipeline.

Sources of borrow material are enough to meet the needs for fill and topsoil for restoration after excavation. Riprap will need to be imported from Durango, Colorado, to meet engineering specifications for armoring drainage channels.

Alternative 5 would be completed as a single phase, and no future removal actions are anticipated. Long-term monitoring and maintenance would not be required; however, short-term maintenance of erosional controls and revegetation efforts would be required. Run-on water control berms, drainage ditches, and sediment detention basins would be repaired as necessary. Temporary range fencing around the restored site would also be checked and repaired as necessary.



The Clean Harbors RCRA Subtitle C hazardous waste disposal facility is currently in compliance with its operating permit and with the CERCLA Off-Site Rule. Because all waste would be disposed of off site, reliance on the disposal capacity of the Clean Harbors facility brings uncertainty to the availability of services at the time of the removal action. A change to the disposal facility or additional disposal facilities could be selected in the action memorandum if necessary.

Administrative Feasibility (Rating: Good) – Implementation of Alternative 5 would require coordination between USEPA, NNEPA, and NAMLRD to address federal and tribal ARARs, but federal permits for onsite actions under CERCLA are not required. General construction permits and environmental reviews may be required from the Navajo Nation. Finally, negotiations with the Navajo Nation or other landowners with potential offsite soil borrow sources would need to be conducted and agreements crafted.

Offsite disposal of materials from a CERCLA site must comply with the CERCLA Off-Site Rule. The Clean Harbors RCRA Subtitle C hazardous waste disposal facility currently has approval under the Off-Site Rule and would need to maintain such approval.

The entity responsible for the short-term surveillance of site restoration features would maintain various plans and conduct periodic inspections and reviews, including a SWPPP overseen by NNEPA (to verify that restoration is protective of surface water quality).

4.3.5.3 Costs

Overall, Alternative 5 has an average costs among the alternatives because of the short-term (10-year) site restoration O&M costs even after trucking costs and Clean Harbors RCRA Subtitle C hazardous waste facility disposal fees. The overall effectiveness of Alternative 5 is rated **Average** (after the **Very Poor** rating for short-term is combined with the **Very Good** rating for long-term effectiveness and permanence). The mid-level costs compared with the **Average** overall effectiveness rating means that Alternative 5 is not cost effective, and the cost rating is **Average**.

The total net present value cost for Alternative 5 is estimated at \$2,802,105 using a 3.5 percent discount rate. The net present value cost includes total capital costs (\$2,597,122), and annual O&M costs (\$24,646) for site restoration inspection and maintenance costs over 10 years.

A breakdown of the major cost categories associated with implementing Alternative 5 is presented below. Detailed cost estimates are provided in [Appendix E](#) and [Table E-5](#).



Cost Component	Brodie 1 Mine
Excavated Surface Area (ft ²)	9,702
Excavated Volume (yd ³)	1,310
Capital Costs	
Site Access	\$84,931
Waste Excavation and Loading	\$97,325
Site Restoration	\$141,648
Haul Road Restoration	\$121,674
Waste Hauling to RCRA C Facility	\$332,085
Disposal at RCRA C Facility	\$171,938
Subtotal Construction Costs	\$550,472
Non-Construction	\$1,647,520
Total Capital Costs	\$2,058,075
O&M Costs	
Annual Site Restoration (10 years)	\$24,646
Total Annual O&M Costs	\$24,646
NPV Costs	
10-Year Site Restoration	\$204,983
Total NPV Costs	\$2,802,105

Notes:

ft² Square feet

NPV Net present value

O&M Operation and maintenance

yd³ Cubic yard

5.0 NAHAT'A - COMPARATIVE ANALYSIS OF ALTERNATIVES

This section presents the approach for the comparative analysis of alternatives and a summary of the analysis. The comparative analysis includes the evaluation of the relative effectiveness, implementability, and cost between alternatives.

5.1 COMPARATIVE ANALYSIS APPROACH

The final step of this AAM is to conduct a comparative analysis of the removal action alternatives. This analysis evaluates each alternative's strengths and weaknesses relative to the other alternatives in achieving RAOs. The comparative analysis ranks the effectiveness, implementability, and cost of each alternatives as very poor, poor, average, good, or very good for each criterion. An explanation of the evaluation and ranking criteria are presented in [Section 4.3](#). Once completed, the analysis will be used to support risk managers and stakeholders in the selection of a preferred removal action alternative for the Brodie 1 Mine. Tribal, supporting agency, and public acceptance will be evaluated after stakeholder comments have been received on this AAM.

In addition, based on USEPA (2016) guidance, five key elements in greener cleanup activities should be considered throughout the remedy selection process. USEPA's (2012) five key elements are to:

- Minimize total energy use and maximize renewable energy use
- Minimize air pollutants and carbon dioxide equivalent emissions
- Minimize water use and negative impacts to water resources
- Improve materials management and waste reduction efforts by reducing, reusing, or recycling whenever feasible
- Protect ecosystem services

5.2 SUMMARY OF ANALYSIS

All alternatives except for Alternative 1 meet the threshold criterion of protectiveness of public health and the environment. [Table 17](#) summarizes the comparative rating of alternatives.

5.2.1 Effectiveness

Effectiveness comprises two threshold criteria (protectiveness and compliance with ARARs), and includes short- and long-term effectiveness and permanence of the remedy. Overall effectiveness is rated **Very Poor** for Alternative 1, **Good** for Alternative 2, **Average** for Alternative 3, **Good** for Alternative 4, and **Average** for Alternative 5. Individual criteria and ratings contributing to the overall ratings are discussed below.

5.2.1.1 Overall Protectiveness of Human Health and the Environment

All alternatives except for Alternative 1 are protective of public health and the environment.

5.2.1.2 Compliance with ARARs

All alternatives except for Alternative 1 would be performed in compliance with federal and tribal ARARs identified in [Table 13](#), [Table 14](#), and [Table 15](#).

5.2.1.3 Short-Term Effectiveness (during Removal Action)

Short-term effectiveness comprises the following criteria: protection of the community and workers during the removal action, environmental impacts, greener cleanups analysis, and time to meet RAOs. Overall short-term effectiveness is rated **Very Good** for Alternative 1, **Good** for Alternative 2, **Average** for Alternative 3, **Poor** for Alternative 4, and **Very Poor** for Alternative 5.

Protection of the Community during Removal Action

Alternative 2 (access route away from the community) is rated **Average**. This alternative creates the least traffic and dust impacts to the community as truck traffic would only be increased on the main access road to transport equipment and construction materials for excavation and burial cell construction. No excavated waste would be hauled through the community. Dust impacts would be limited to the excavation and constructed traffic on the local access road. No waste hauling miles through the community would also result in less traffic accidents.

Alternative 3 (haul route away from the community) is rated **Average**. Excavated waste from the Brodie 1 Mine will be hauled on a portion of Indian Route 35 and on dirt roads that does not directly pass through the community to the regional repository near Block K Mine. This alternative could lead to more traffic impacts to the community than Alternative 2 because excavated waste would be hauled 6 miles from Brodie 1 Mine to the regional repository. Dust impacts would be limited to the excavation and loading areas and the 5 miles of dirt access roads from Brodie 1 Mine to the regional repository. Construction traffic miles would be about the same as Alternative 2 due to cost share for repository construction, therefore an increase in traffic accidents is not anticipated.

Alternatives 4 and 5 (haul routes through the community) have the highest impact on traffic, increased truck emissions, and increased possibility of traffic accidents. Dust impacts would occur during excavation, waste loading, and haul on local access roads. Excavated waste will be hauled on Indian Route 35 through the community and on state highways to off-Navajo Nation disposal facilities located 63 and 565 miles away. Alternative 4 would have a marginal possible increase of traffic accidents and Alternative 5 would increase the possibility of traffic accidents by a factor of 4 over Alternative 2. Therefore, Alternative 4 is rated **Average** and Alternative 5 is rated **Poor** because of the longer roundtrip distance to the disposal facility.

The Alternative 1 is rated **Very Good** as no removal activities would be conducted to impact the community.

Protection of Workers during Removal Action

Worker protection primarily involves radiation exposure, dust inhalation hazards, physical injury, and traffic accidents. All action alternatives involve the same degree of excavation work;

therefore, all action alternatives have equal amounts of potential radiation exposure, potential dust inhalation hazards, and potential for injury to workers. However, Alternatives 2 and 3 involve rehabilitation of a burial cell or construction of a repository, which introduces an additional level of threat to workers because of additional handling activities and duration of exposure during consolidation and capping.

Even though Alternatives 2 and 3 pose an additional hazard associated with additional handling and exposure to waste during consolidation and capping, the long haul distances for off-Navajo Nation disposal pose the greatest accident threat to truck drivers. Therefore, Alternative 4 with the shorter haul distance (63 miles one way) is rated **Poor**, and Alternative 5 with a longer haul distance (565 miles one way) is rated **Very Poor**. Alternative 2 has a smaller burial cell footprint than Alternative 3 and no hauling and is rated **Good**. Alternative 3 is rated **Average** because of the construction of a larger repository and marginally longer haul distance (6 miles one way) than Alternative 2. The Alternative 1 is rated **Very Good** as no removal activities would be conducted to impact workers.

Environmental Impacts

Shorter haul distances and construction durations minimize the potential for construction-related environmental impacts to occur both on public roads and off road and in the construction areas that would require mitigation. These impacts may include residual track-in and track-out effects of soil and mud, noise, nuisance, soil spills during waste hauling, sedimentation of local drainages, and harmful emissions. In addition, construction of a burial cell or repository increases the amount of construction and, therefore, increases environmental impacts while offsite disposal increases fuel consumption and greenhouse gas emissions. Long-term O&M (1,000 years) is expected to have an impact on alternative footprints. An environmental footprint analysis was also conducted and is summarized below under greener cleanups analysis.

Greener Cleanups Analysis. An environmental footprint analysis was conducted for the removal action elements common to all alternatives and for implementation of the four disposal alternatives. The analysis focused on the environmental footprint associated with five main categories: energy use, air pollutants and greenhouse gas emissions, water use and impacts to water resources, materials management and waste reduction, and land management and ecosystems protection.

- *Energy and Emissions.* Among the common elements applicable to all action alternatives, rehabilitating and extending the access road to the lower portion of the site and onsite excavation and restoration activities resulted in a moderate amount of energy use and generated emissions. Over the short term, Alternatives 2 and 3 have a **small** energy and emissions footprints (4,600 and 3,600 gallons, respectively) due to onsite and short haul distance to the regional repository.

However, over the long term, Alternatives 2 and 3 have the **largest** energy and emissions footprint because of the number of onsite visits required to inspect and manage the burial cell and repository caps over 1,000 years (46,000 gallons of fuel). Alternative 4 has a **small** energy and emissions footprint (5,000 gallons of fuel) and Alternative 5 has a **medium** footprint (21,400 gallons of fuel) because of the relatively short (10-year) site

inspection visits for site restoration even after longer offsite haul distances are considered.

Best management practices (BMP) to consider include using local labor for inspections and reducing the number of inspections required per year to reduce the footprint, and using electric, hybrid, or hydrogen fuel cell vehicles instead of conventional gasoline or diesel vehicles to reduce emissions. Implementing an idle reduction plan could also reduce emissions.

- *Water Resources.* Among the common elements applicable to all alternatives, water use for dust control during road work, waste excavation and loading, backfilling, and site restoration resulted in the more water use than any of the disposal components of the alternatives. Alternatives 2 and 3 require water for waste compaction, while Alternatives 4 and 5 do not because of offsite disposal. Alternatives 3, 4, and 5 require water for dust control on haul roads, while Alternative 2 does not because waste would remain on site. All alternatives would require use of NTUA water or groundwater. Overall, because of the relatively small construction area and volume of waste handled, there is no relative difference in the **small** water resource footprint between alternatives.

BMPs to consider include using magnesium chloride and polymers for dust aggregation and suppression.

- *Materials Management.* Among the common elements applicable to all alternatives, long distance transportation of engineered riprap for site restoration resulted in the largest energy use and emissions generated related to materials import. Alternative 2 requires import of gravel for onsite cap construction. Alternative 3 requires hauling of waste from the Brodie 1 Mine and import of gravel for regional repository construction. Borrow soil for site restoration and capping will be from on site. Alternatives 4 and 5 will require hauling of waste for offsite disposal, which would be generally equivalent to the volume of imported materials under Alternatives 2 and 3. Overall, because of the relatively small construction area and volume of waste handled, all alternatives have a **small** material management footprint.

BMPs to consider include reusing clean site materials, selecting products that are local (borrow pits and quarries), using alternate local materials with similar performance standards as import materials, and identifying an alternate disposal facility closer to the site to reduce fuel consumption and emissions.

- *Land Management and Ecosystems Protection.* Among the common elements applicable to all alternatives, removal of habitat during site excavation and noise and activity disturbance of sensitive biological species are the greatest ecosystem impacts. Alternatives 4 and 5 have the **smallest** land management and ecosystems protection footprint as all waste will be hauled off site. Alternatives 2 and 3 have a **medium** footprint because of noise and activity disturbance of sensitive biological species during extended construction and the site future land use would be limited by burial cell and repository footprints. Minimal loss of grazing land is expected over the long term.

BMPs to consider include minimizing burial cell or repository size; using geomorphic grading to reduce visual impacts; minimizing clearing of shrubs, grasses, and forbs; scheduling work to minimize impact on sensitive species; and using a suitable mix of shrubs, grasses, and forbs to improve biodiversity during restoration.



Greener Cleanups Summary. Alternatives 2 and 3 rated **Good** for the short term because of the shorter on-Navajo haul distances than off-Navajo Nation hauling under Alternative 4 and 5. Alternative 4 is rated **Poor** because of longer haul distance to a disposal facility than Alternatives 2 or 3, but a much shorter haul distance than Alternative 5. Alternative 5 rated as **Very Poor** because of the longest haul distance to the disposal facility. Alternative 1 is rated **Very Good** as no removal action would be performed.

Over the long term, Alternatives 2 and 3 rated **Poor** because the 1,000-year O&M duration yields a larger energy and greenhouse gas footprint than off-Navajo Nation hauling under Alternative 4 and 5. In addition, Alternative 2 and 3 could limit future land uses because of the need to protect burial cell and repository caps. Alternatives 4 and 5 are rated **Good** over the long term because no O&M is required and neither would limit future land uses.

Time until RAOs Are Achieved

All action alternatives could be completed in approximately 1 to 2 months, depending on schedule-limiting factors such as truck availability, monsoon rains, and snowfall.

5.2.1.4 Long-Term Effectiveness and Permanence (after Removal Action)

For all action alternatives, waste removal or containment from source areas would reduce the magnitude of residual risk to background levels for radionuclides. Noncancer hazards would be removed, and risk to ecological receptors would be reduced to levels below known effects concentrations and background levels. None of the alternatives reduce the toxicity, mobility, or volume through treatment.

Alternatives 4 and 5 are rated **Very Good** as sources of risk at the site as waste would be removed and disposed of off the Navajo Nation. However, the off-Navajo Nation milling process increases the toxicity of the waste at the tailings disposal facility. The cap and liner at the tailings disposal facility would eliminate exposure pathways. Alternatives 4 and 5 would also allow for unrestricted future use of the entire site. Removing waste from the Navajo Nation eliminates the long-term surveillance requirements and long-term environmental footprints associated with a burial cell or repository under Alternatives 2 and 3. Neither Alternative 4 or 5 would require long-term site inspections or repairs and associated increased possibility of traffic accidents in comparison to Alternatives 2 and 3.

Alternatives 2 and 3 would consolidate all waste in a burial cell or repository. Permanence of risk reduction would rely on the burial cell cover or repository design standards to minimize long-term maintenance, but long-term surveillance of the burial cell or repository would still be required. Alternative 3 is rated **Good** because a repository with waste above ground offers more control over potential infiltration from the sides than a burial cell with waste below ground surface. Alternative 2 is rated **Average** because a burial cell with waste below ground surface offers less control of potential infiltration from the sides than a repository with waste above ground. Although the burial cell and repository (Alternatives 2 and 3) are expected to be fully protective in both the short and long term, the ET cap will require a long-term maintenance and monitoring commitment. Replacement of burial cell or repository components would not be required because their lifespan is indefinite, especially under a monitoring and maintenance regime. Over the long term, additional accidents and fatalities could also result from site

inspections and repairs during long-term O&M of the burial cell and regional repository caps. Alternatives 2 and 3 would have large energy and greenhouse gas footprints because of the high fuel consumption and emissions over the 1,000-year O&M duration. An estimated 2 in 10 risk of an additional accident and 6 in 1,000 risk of an additional fatality for the 405,000 miles traveled over 1,000 years from on-highway traffic accidents are possible.

Alternative 1 is rated **Very Poor** because no removal action would be performed. Human health risk may be partially reduced through increased awareness of risks, but no reduction in risk to the ecosystem would occur. Uncontrolled and untreated waste would remain and continue to be accessible by humans and animals and subject to potential migration to uncontaminated or less contaminated areas.

5.2.2 Implementability

Implementability comprises the two criteria: technical feasibility and availability of services and materials, and administrative feasibility. Overall implementability is rated **Very Good** for Alternative 1, **Very Good** for Alternative 2, **Good** for Alternative 3, **Very Good** for Alternative 4, and **Very Good** for Alternative 5. Individual criteria and ratings contributing to the overall ratings are discussed below.

5.2.2.1 *Technical Feasibility and Availability of Services and Materials*

Action alternatives consist mainly of simple earthwork and material hauling. The alternatives are technically feasible with labor available through the local and regional market and equipment and materials located 1.5 to 2 hours away.

The action alternatives would be completed as a single phase, and no future remedial actions are anticipated. Short-term monitoring of site restoration features will occur under all action alternatives while long-term monitoring and maintenance, particularly inspection and repair of erosional features and controls and revegetation, would be required for Alternate 2 (onsite burial cell) and Alternative 3 (regional repository). Experienced contractors, construction equipment, and materials are available with the region.

Among the action alternatives, Alternatives 4 and 5 are the most technically feasible to implement as all waste is removed from the Brodie 1 Mine; however, milling and disposal is more technically complex than disposal in a hazardous waste disposal facility. However, the exclusive reliance on the operational capacity of the White Mesa Mill brings uncertainty to the availability of services at the time of the removal action. No other mill facilities are in operation in the region. Therefore, Alternative 4 is rated **Good** while Alternative 5 is rated **Very Good**.

Alternatives 2 and 3 are both rated **Very Good**. Both alternatives are technically feasible as waste is consolidated on site in a burial cell or in the on-Navajo Nation repository. Design methods, construction practices, and engineering requirements are well documented and understood. Because all waste under the Alternatives 2 and 3 would be disposed of on site or on the Navajo Nation, no reliance on the treatment, storage, or disposal capacity of contracted services would be required. Alternative 2 would require no hauling and less complex construction than Alternative 3, but a regional repository would consolidate O&M activities in comparison to multiple onsite actions.

Alternative 1 is readily implementable and involves no construction and is rated **Very Good**. Alternative 1 would not impact the ability to conduct removal or remedial actions in the future. No services or materials would be needed because no removal action would be performed.

5.2.2.2 Administrative Feasibility

Administratively, Alternatives 4 and 5 are rated **Good** as they require the least amount of design, permitting, and approvals from and coordination with agencies as no onsite burial cell or on-Navajo Nation repository would be involved. Post-remedy inspections, reviews, and land use controls would be limited in comparison to onsite burial cell capping and on-Navajo Nation repository construction. However, limitations and delays on waste acceptance at off-Navajo Nation facilities are possible because of the volume of waste or disposal facility permit limitations.

Alternative 2 is rated **Very Good** as less design, permitting, approvals, and coordination with agencies is required for burial cell cover construction in comparison to Alternative 3, less O&M activities are required for a smaller volume of waste and footprint, and fewer potential challenges with future removal actions are expected than with a larger regional repository. The burial cell under Alternative 2 is located away from the community whereas the regional repository under Alternative 3 is located closer to and waste must pass through the community. Alternative 3 would also involve waste haulage from other mine sites, requiring approval and coordination that would not be required under Alternative 2. For these reasons, Alternative 3 is rated **Average**.

Alternative 1 is rated **Very Good** as taking no action is always feasible. However, future removal or remedial actions could still occur under CERCLA or through other actions of the Navajo Nation or Tronox.

5.2.2.3 Tribal and Supporting Agency Acceptance

Acceptance by the Navajo Nation and supporting agencies is an additional criterion that will be addressed in the final EE/CA report and action memorandum after stakeholder comments have been received on this AAM.

5.2.2.4 Community Acceptance

Acceptance by the Sweetwater and Teec Nos Pos Chapter communities is an additional criterion that will be addressed in the final EE/CA report and action memorandum after public comments have been received on this AAM.

5.2.3 Projected Costs

A summary of the cost for each alternative are presented below. Alternative costs are presented as a rating (comparing each alternative to the others) and as the total estimated cost based on 2021 price evaluations for each alternative.



Alternative	Cost Rating	Total Estimated Cost (2021 million dollars)
1	Very Good	\$0
2	Poor	\$3.1 M
3	Average	\$2.7 M
4	Good	\$2.3 M
5	Average	\$2.8 M

Note:

Higher cost alternatives rate lower in cost ratings, which is consistent with the rating scheme where low = less desirable.

Present values, including O&M costs, for each action alternative using a baseline 10-year project duration for site restoration and 1,000-year (required under UMTRCA 40 CFR § 192[d] Part A) project duration for onsite consolidation and capping and regional repository (Alternatives 2 and 3, respectively) at a 3.5 percent discount rate (30-year rolling average) (Office of Management and Budget 2020) are summarized below.

Alternative	Capital Cost	Yearly Site O&M Cost (10 years)	Present Value (10 years) 3.5% discount rate	Yearly Cap O&M Cost (1,000 years)	Present Value (1,000 years) 3.5% discount rate
1	\$0	\$0	\$0	\$0	\$0
2	\$2,240,257	\$24,646	Not Applicable	\$22,899	\$3,099,496
3	\$2,030,876	\$24,646	Not Applicable	\$16,349	\$2,703,132
4	\$2,058,075	\$24,646	\$2,263,058	Not Applicable	Not Applicable
5	\$2,597,122	\$24,646	\$2,802,105	Not Applicable	Not Applicable

Note:

O&M Operation and maintenance

Alternative 1 is the least expensive because no construction and O&M costs are incurred and is rated **Very Good**. The capital costs for Alternative 2 are elevated with respect to Alternative 3 because of the relatively small amount of waste being consolidated on site. Alternatives 2 and 3 are similar in capital costs, but Alternative 2 long-term O&M costs are 40 percent higher than those of Alternative 3 on a volumetric cost share basis (waste from multiple mines). Therefore, Alternative 2 is rated **Poor** while Alternative 3 is rated **Average**. Long-term O&M costs at a regional repository would be more cost effective under Alternative 3 because costs are shared over more mine sites.

Alternative 4 has the lowest net present value and is rated **Good** with capital costs essentially equivalent to Alternative 3, both of which are about 10 percent less than Alternative 2. Because of the small amount of waste being addressed, offsite disposal with a short haul distance is less expensive than consolidation and capping on site or in a regional repository. Alternative 5 is rated **Average** with the highest capital cost of the alternatives, but with a lower net present value than Alternative 2 because no long-term O&M would be required. Short-term O&M costs for site restoration activities under Alternatives 4 and 5 are the same. For Brodie 1 Mine, Alternative 4 offers the lowest cost and does not require any long-term O&M activities.

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FIGURES

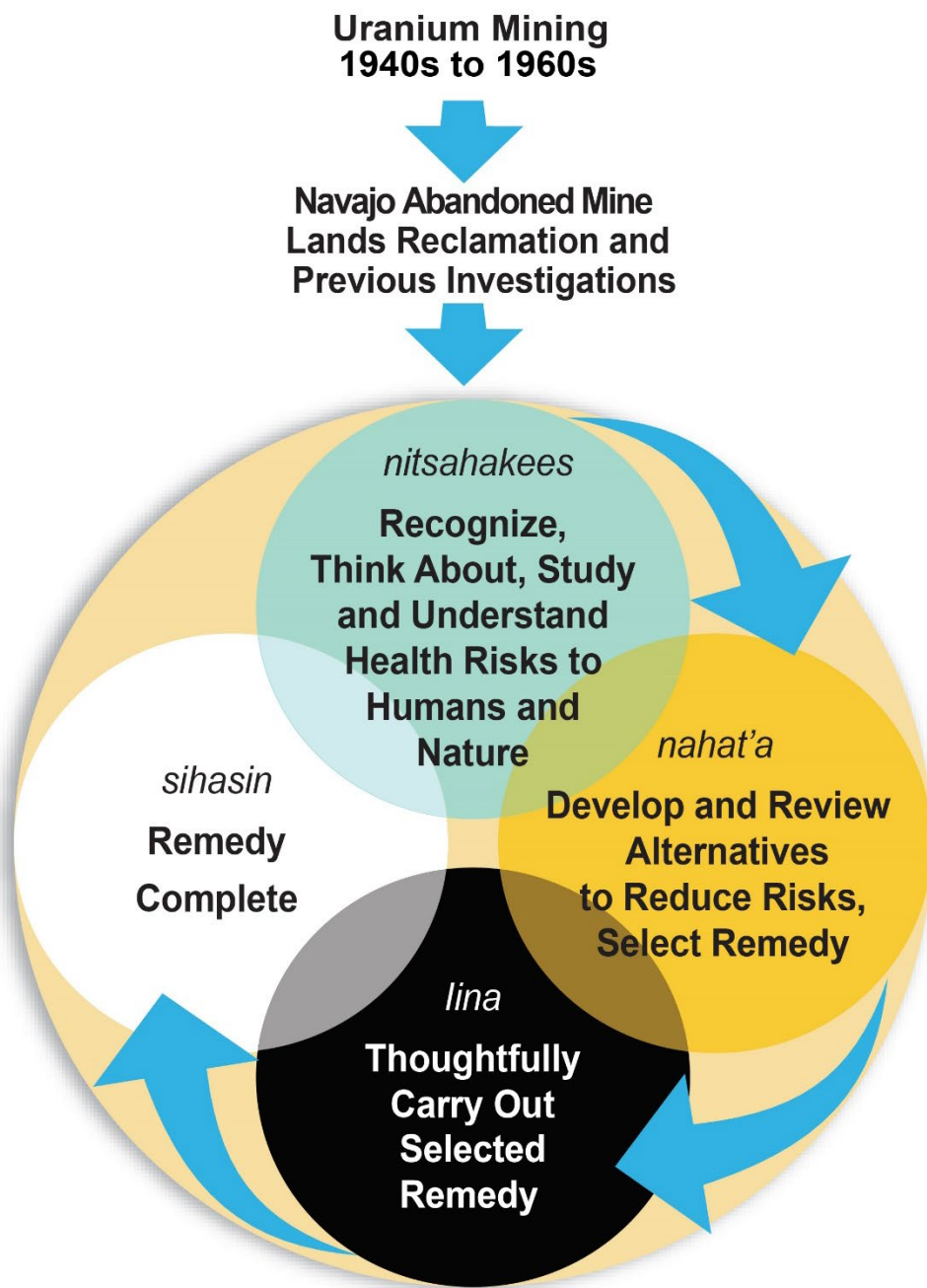
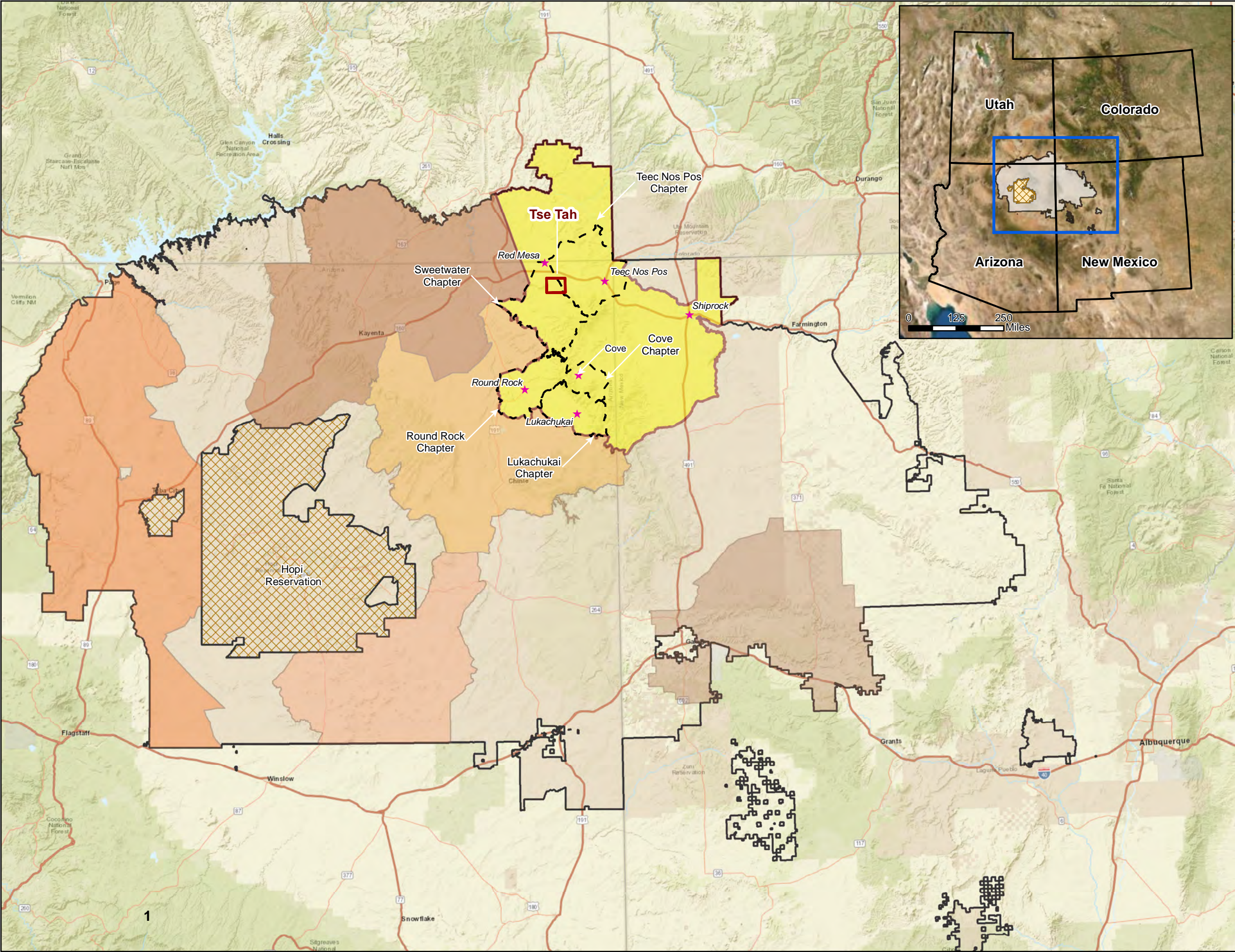


Figure 1. Navajo EE/CA Decision Process



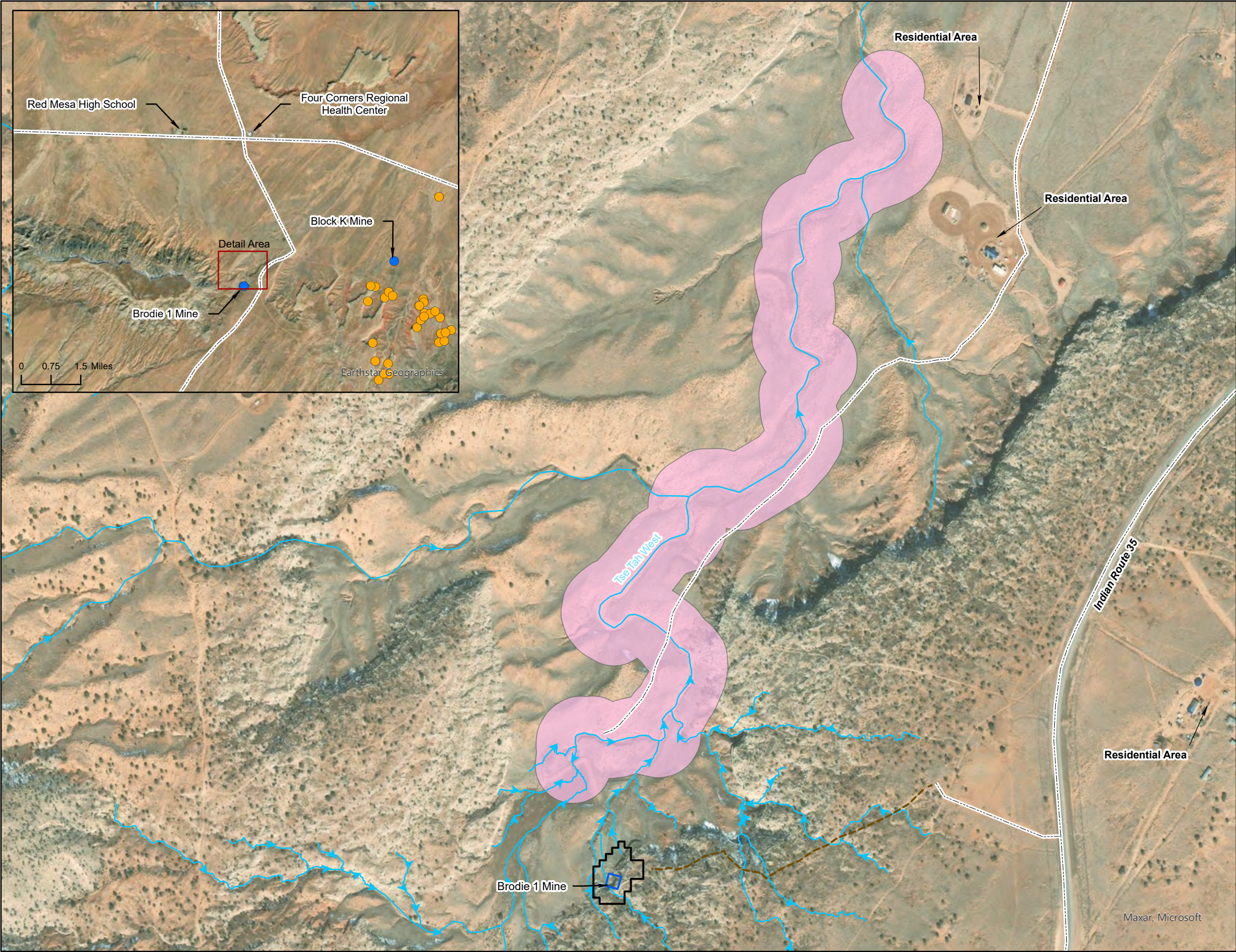
- ★ Populated Place
- ⬜ Affected Chapter Boundary
- ⬜ Navajo Nation Boundary
- ▨ Hopi Reservation
- ▭ Removal Site Evaluation Investigation Region
- Navajo Nation Abandoned Uranium Mine Regions**
 - Yellow Northern Region
 - Light Orange Central Region
 - Medium Orange Eastern Region
 - Dark Orange North Central Region
 - Light Brown Southern Region
 - Dark Brown Western Region

1 inch = 25 miles
1:1,584,000

25 12.5 0 25 Miles

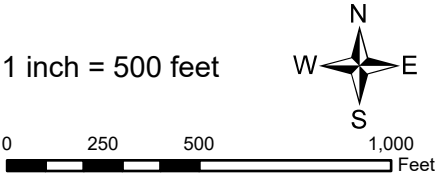
REGIONAL LOCATION

Prepared For: U.S. EPA Region 9	
Prepared By: TETRA TECH 1999 Harrison Street, Suite 500 Oakland, CA 94612	
Task Order No.: 0016	Contract No.: EP-S9-17-03
Location: NAVAJO NATION	Date: 9/27/2021
Coordinate System: NAD 1983 UTM Zone 12N Transverse Mercator	Figure No.: 2




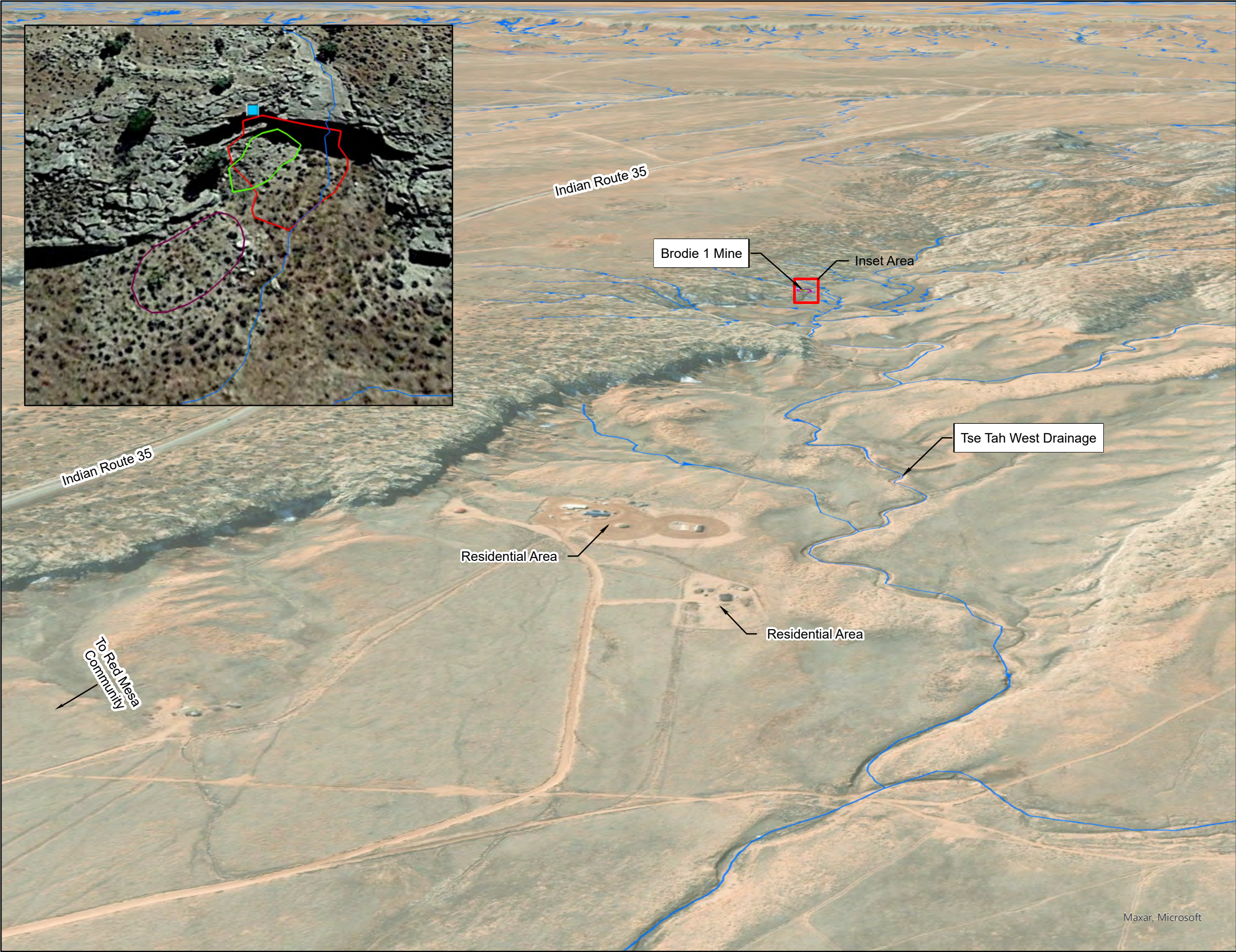
- AUM Site**
- Tronox
 - Cyprus Amax
 - Brodie 1 Mine¹
 - RSE Survey Area
 - Drainage Exposure Unit
 - Access Route - Foot
 - Access Route - Vehicular
 - Drainage

Notes:
¹Boundary is from Neptune and TSG (2018).
Neptune Neptune and Company, Inc.
RSE Removal site evaluation
TSG TerraSpectra Geomatics



BRODIE 1 MINE ACCESS

Prepared For: U.S. EPA Region 9	Prepared By:
	 TETRA TECH 1999 Harrison Street, Suite 500 Oakland, CA 94612
Task Order No.: 0016	Contract No.: EP-S9-17-03
Location: COVE CHAPTER NAVAJO NATION	Date: 9/24/2021
Coordinate System: NAD 1983 State Plane Arizona East FIPS 0201 Feet Transverse Mercator	Figure No.: 3

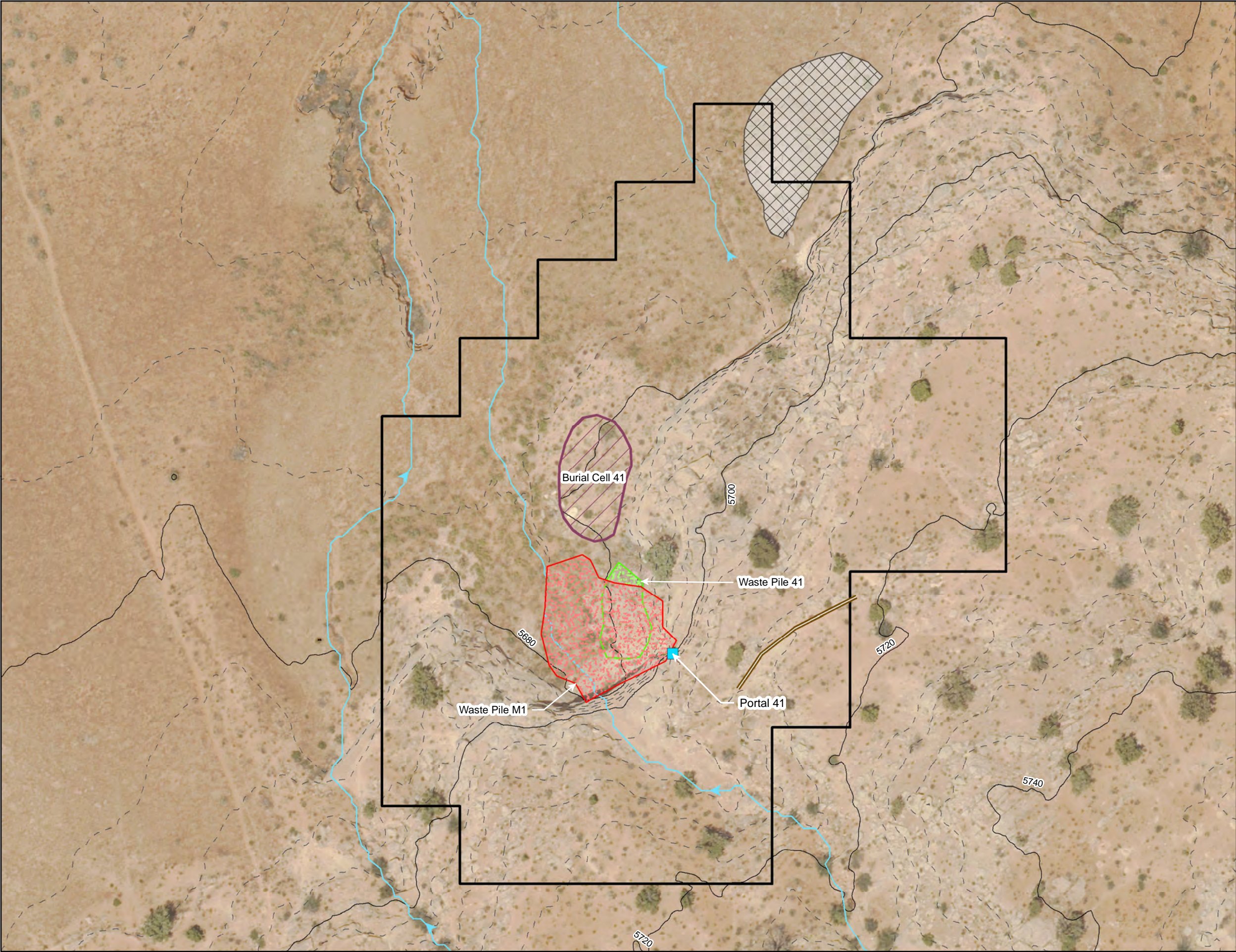


- AUM Site Boundary¹**
- Site Features**
- Site Features
 - Burial Cell
 - Waste Pile - Reclaimed
 - Waste Pile - Unreclaimed
 - Drainage

Notes:
¹Boundary is from Neptune and TSG (2018).
AUM Abandoned uranium mine
Neptune Neptune and Company, Inc.
TSG TerraSpectra Geomatics

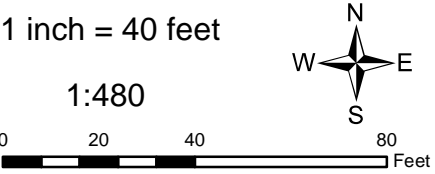
BRODIE 1 MINE LOCATION

Prepared For: U.S. EPA Region 9	Prepared By:
	 TETRA TECH 1999 Harrison Street, Suite 500 Oakland, CA 94612
Task Order No.: 0016	Contract No.: EP-S9-17-03
Location: SWEETWATER CHAPTER NAVAJO NATION	Date: 9/27/2021
Coordinate System: NAD 1983 State Plane New Arizona East FIPS 0201 Feet Transverse Mercator	Figure No.: 4



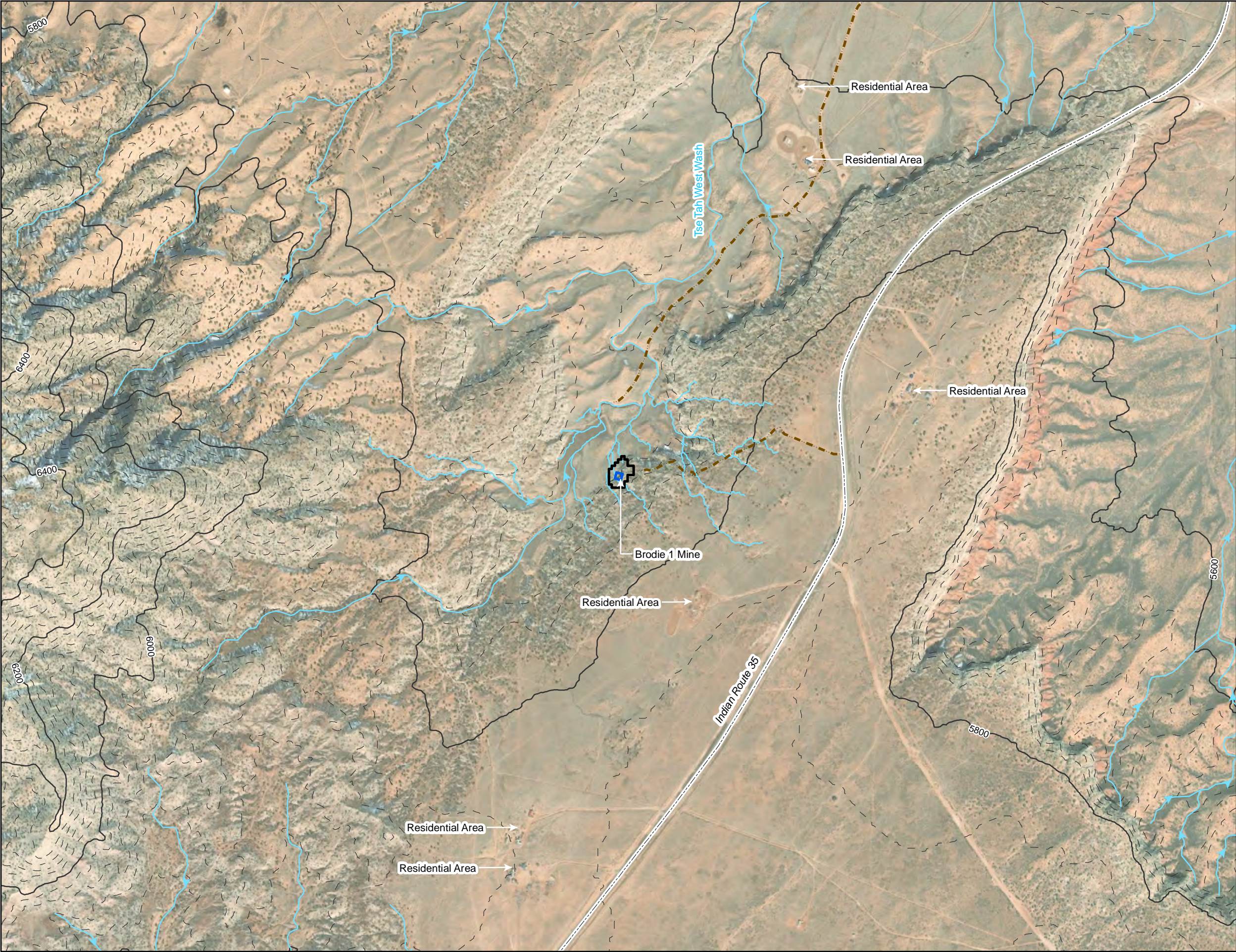
- RSE Survey Area
- Site Features**
- Closed Portal
 - Berm
 - Restricted Area - Cultural
 - Waste Pile - Reclaimed
 - Burial Cell
 - Waste Pile - Unreclaimed
 - 20-Foot Contour
 - 4-Foot Contour
 - Drainage

Note:
RSE Removal site evaluation



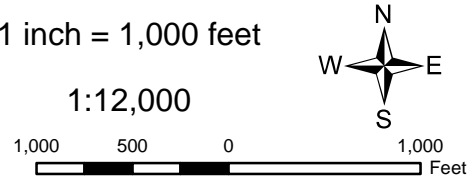
BRODIE 1 MINE FEATURES

Prepared For: U.S. EPA Region 9		Prepared By:	
		 1999 Harrison Street, Suite 500 Oakland, CA 94612	
Task Order No.: 0016		Contract No.: EP-S9-17-03	
Location: SWEETWATER CHAPTER NAVAJO NATION		Date: 9/24/2021	
Coordinate System: NAD 1983 State Plane Arizona East FIPS 0201 Feet Transverse Mercator			Figure No.: 5



- 200-Foot Contour
- - 40-Foot Contour
- Drainage
- Brodie 1 Mine¹
- RSE Survey Area
- - Paved Route
- - Unpaved Route

Notes:
¹Boundary is from Neptune and TSG (2018).
²Boundary is from TSG (2007).
AUM Abandoned uranium mine
Neptune Neptune and Company, Inc.
RSE Removal site evaluation
TSG TerraSpectra Geomatics



BRODIE 1 MINE
TOPOGRAPHY AND HYDROLOGY

Prepared For: U.S. EPA Region 9



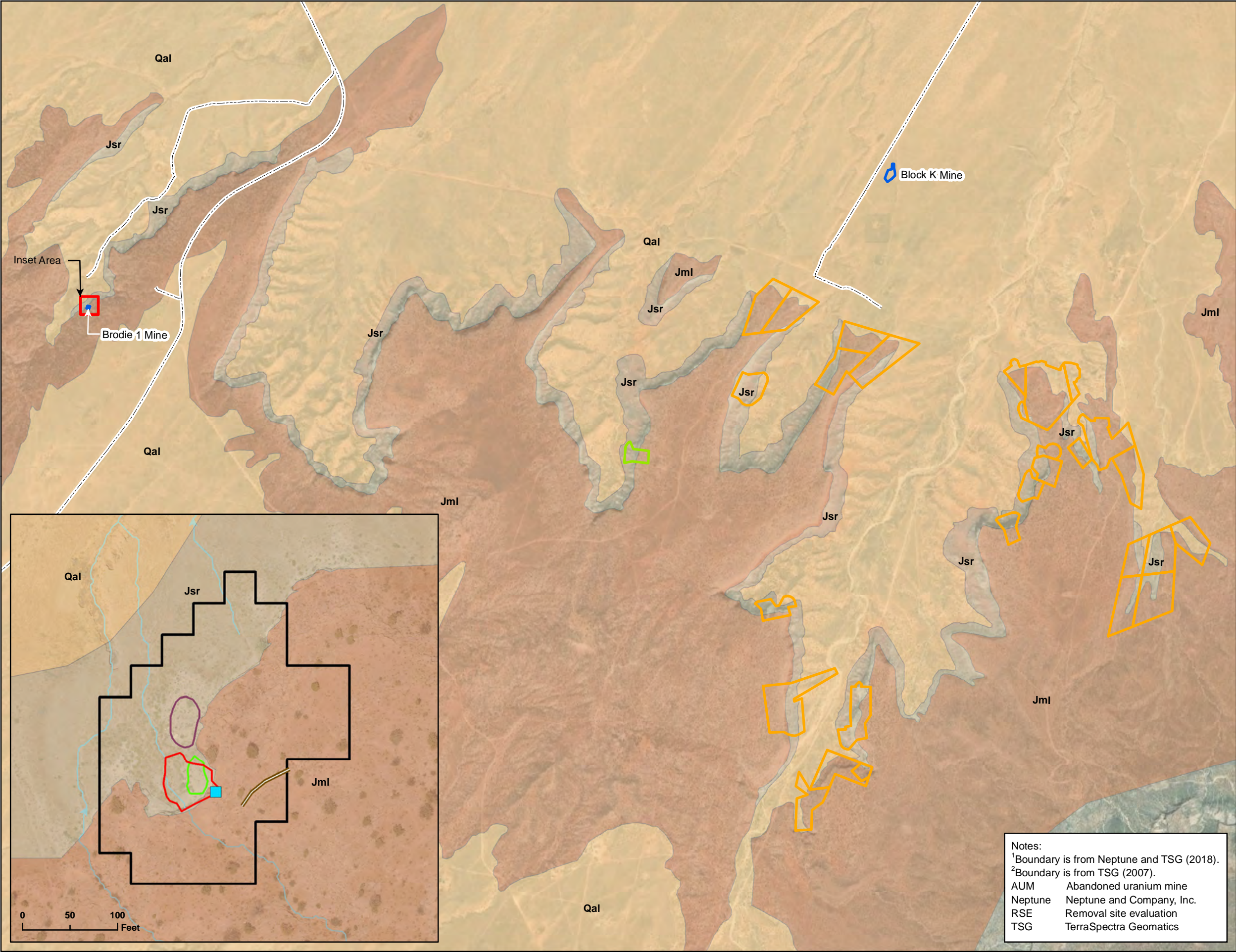
Prepared By:



Task Order No.: 0016	Contract No.: EP-S9-17-03
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Location: SWEETWATER CHAPTER NAVAJO NATION	Date: 9/26/2021
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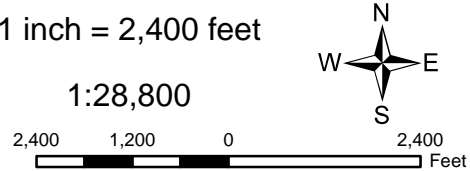
Coordinate System: NAD 1983 State Plane Arizona East FIPS 0201 Feet Transverse Mercator	Figure No.: 6
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- Geologic Units**
- Quaternary Alluvium - Qal
 - San Rafael Group - Jsr
 - Lower Morrison - Jml

- Site Boundaries**
- Tronox AUM¹
 - Cyprus Amax AUM²
 - Other AUM²
 - RSE Survey Area
 - Access Route

- Site Features**
- Closed Portal
 - Berm
 - Waste Pile - Reclaimed
 - Burial Cell
 - Waste Pile - Reclaimed
 - Drainage



TSE TAH REGIONAL GEOLOGY

Prepared For: U.S. EPA Region 9



Prepared By:



Task Order No.: 0016

Contract No.: EP-S9-17-03

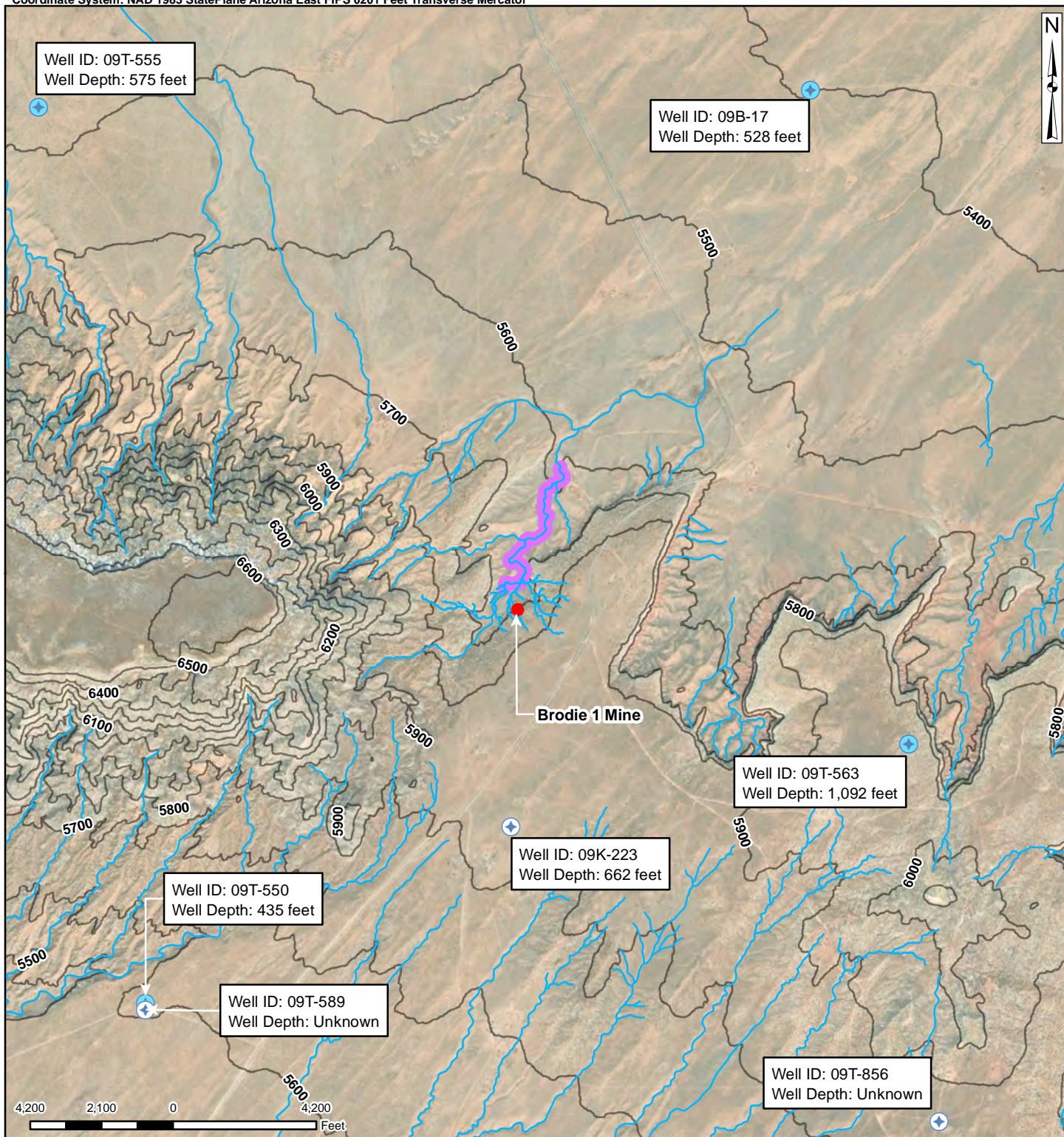
Location: SWEETWATER CHAPTER
NAVAJO NATION

Date: 9/24/2021

Coordinate System:
NAD 1983 State Plane Arizona East
FIPS 0201 Feet Transverse Mercator

Figure No.: 7

Notes:
¹Boundary is from Neptune and TSG (2018).
²Boundary is from TSG (2007).
AUM Abandoned uranium mine
Neptune Neptune and Company, Inc.
RSE Removal site evaluation
TSG TerraSpectra Geomatics



Well Locations

- Livestock Use
- Unknown Use
- Tse Tah West Drainage Exposure Unit
- AUM Site Dry Mine
- Drainage Pathway
- Surface Elevation Contour (100-Foot)

Note:
AUM Abandoned uranium mine

Prepared for: U.S. EPA Region 9



Prepared By:



BRODIE 1 MINE SURFACE WATER AND WELLS

Task Order No.:

0016

Contract No.:

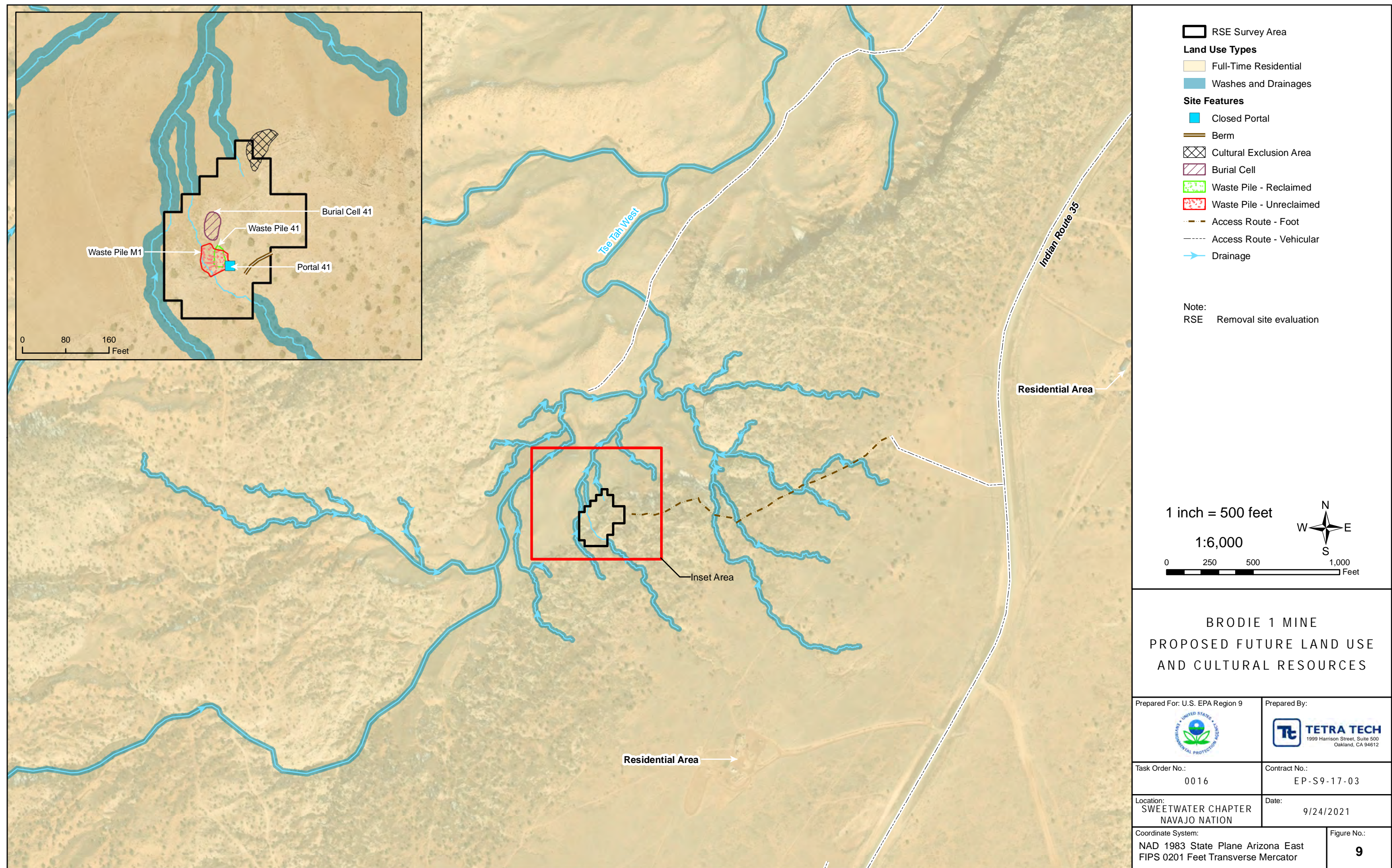
EP-S9-17-03

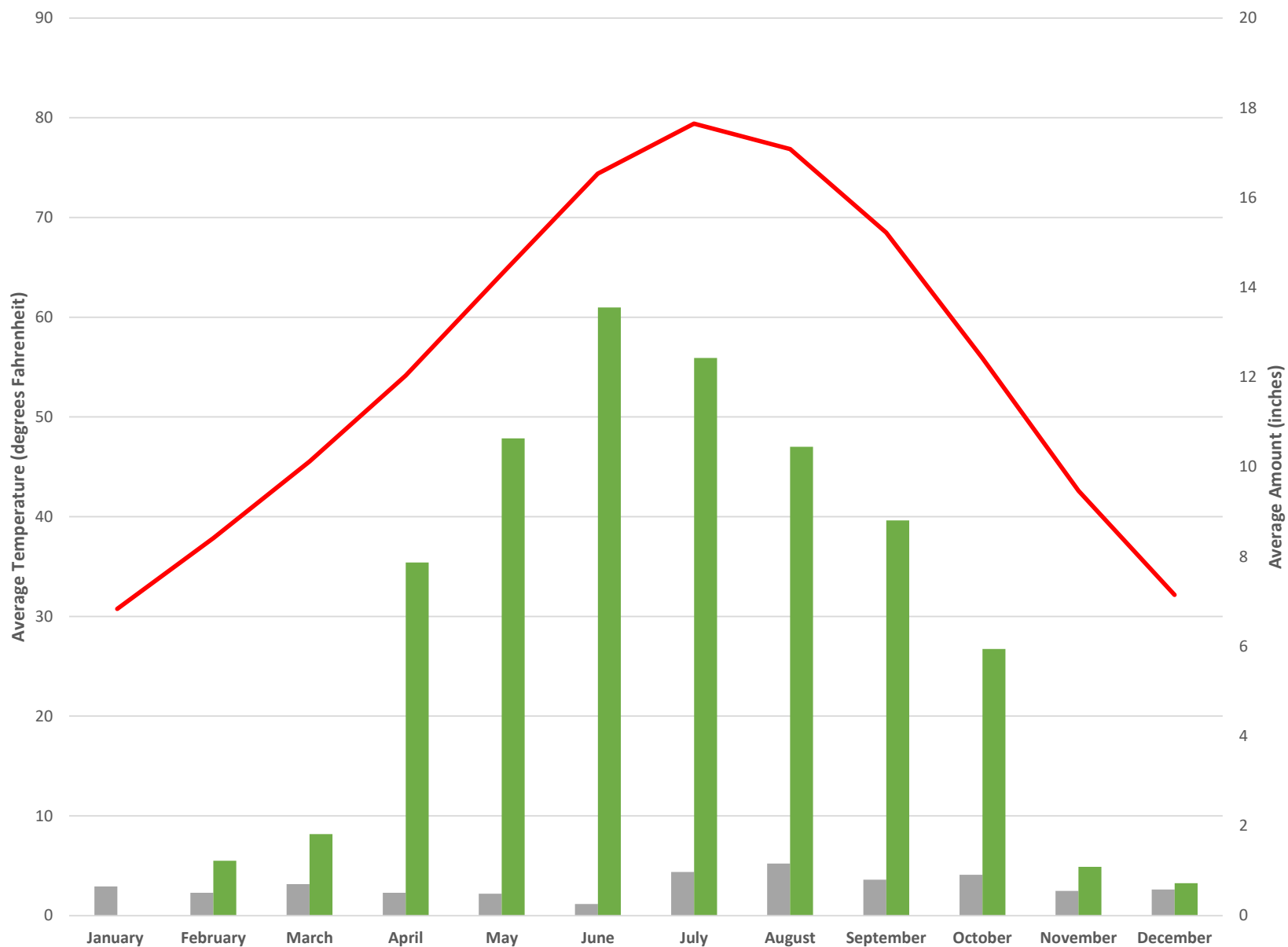
Figure No.:

8

Location:
SWEETWATER CHAPTER
NAVAJO NATION

Date:
9/24/2021





Total Precipitation (1914-2010)¹
 Average Evapotranspiration (Navajo, NM)^{2,3}

Notes:
¹<https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?az8468>
²https://wrcc.dri.edu/Climate/comp_table_show.php?type=pan_evap_avg
³Evapotranspiration average of Navajo, NM (1963-2005), Many Farms, AZ (1955-1975), and Shiprock, NM (1926-2005)

Prepared for: U.S. EPA Region 9



Prepared By:



NORTHERN NAVAJO MONTHLY AVERAGE TEMPERATURE, PRECIPITATION, AND EVAPOTRANSPIRATION

Task Order No.: 0016

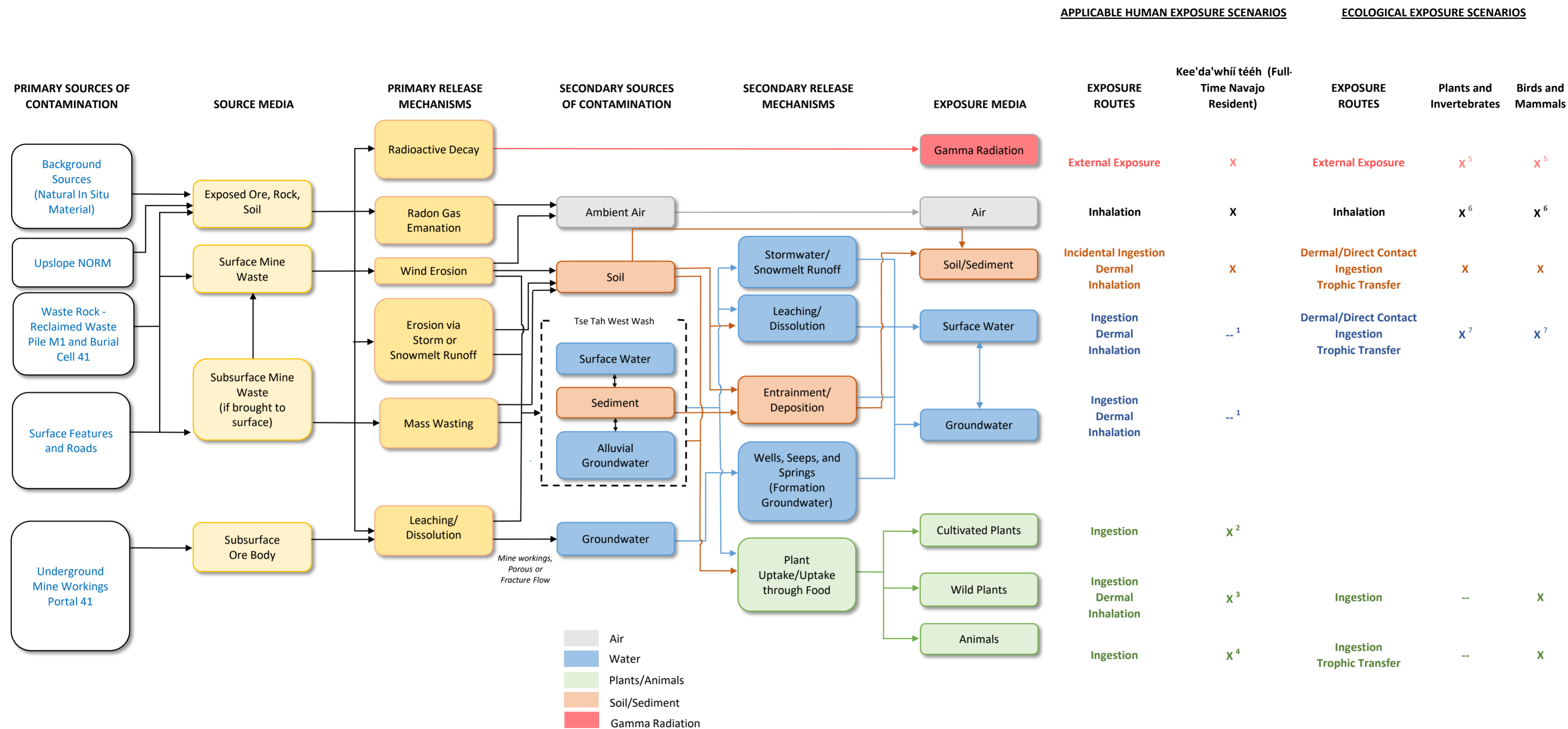
Contract No.: EP-S9-17-03

Figure No.:

10

Location:
TEEC NOS POS CHAPTER NAVAJO NATION

Date:
9/24/2021



Notes:

Conceptual site model wire diagram was adapted from Neptune and Company, Inc. and TerraSpectra Geomatics. 2018. "Final Preliminary Conceptual Site Model." Cove Chapter Abandoned Uranium Mines Conceptual Site Model Development, Navajo Nation, Cove Chapter, Apache County, Arizona. July.

X Indicates the exposure pathway is potentially complete and evaluated in the risk assessment, except as noted.

-- Indicates the exposure pathway is not complete or *de minimus* and is not evaluated in the risk assessment

¹ The human health risk evaluation does not include ingestion of surface water or groundwater by humans or animals.

² The human health risk evaluation includes ingestion of select cultivated plants (crops) by this receptor. Scenario inputs provided by Navajo Nation Environmental Protection Agency.

³ The human health risk evaluation includes ingestion, dermal (metals only), and inhalation of select wild (cultivated plants (crops) by this receptor. Scenario inputs provided by Navajo Nation Environmental Protection Agency.

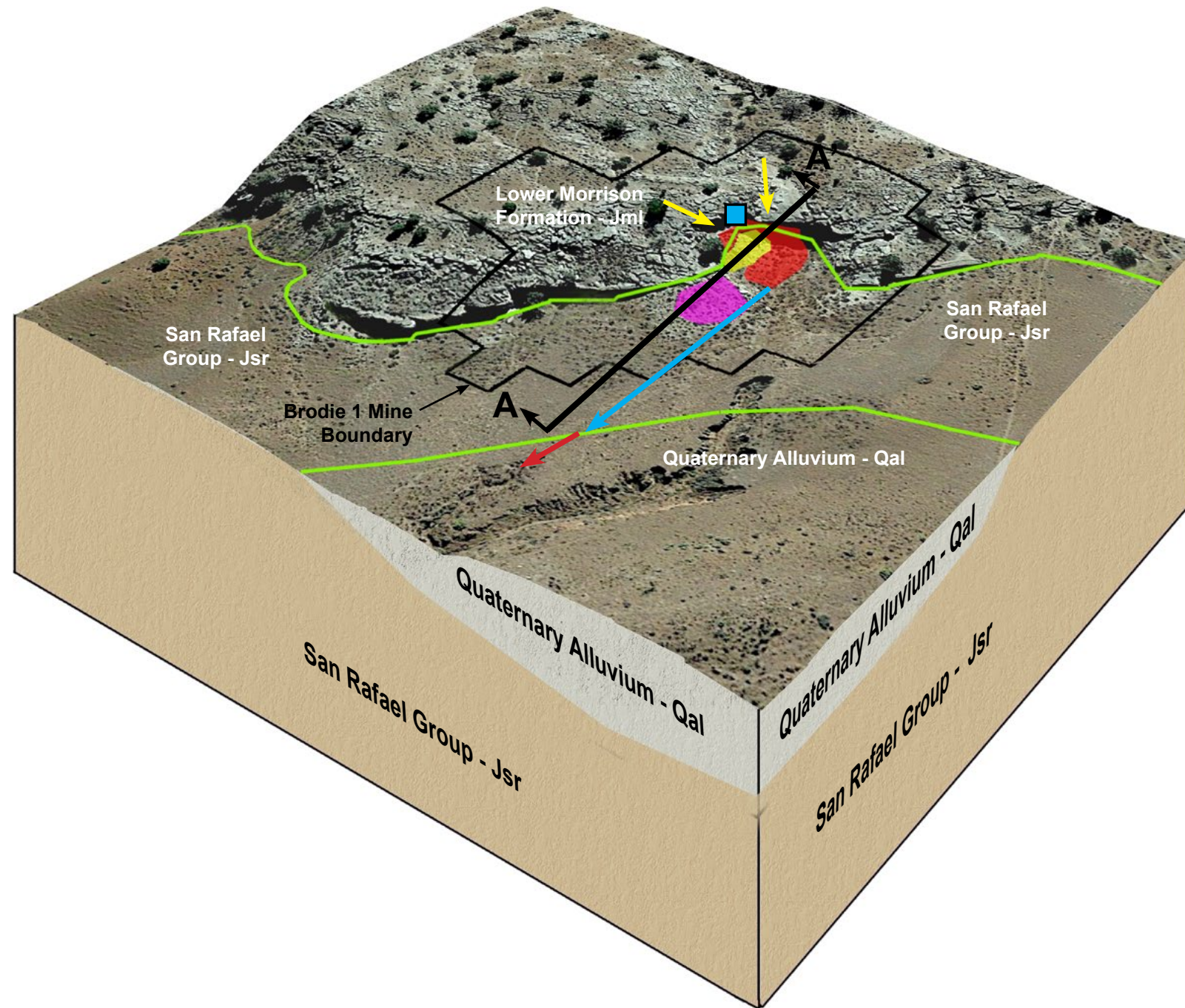
⁴ The human health risk evaluation includes ingestion of home-raised animals (meat, milk, and eggs) and hunted animals (meat only) for this receptor. Scenario inputs provided by Navajo Nation Environmental Protection Agency.

⁵ The ecological risk evaluation does not include evaluation of external exposure to gamma radiation.

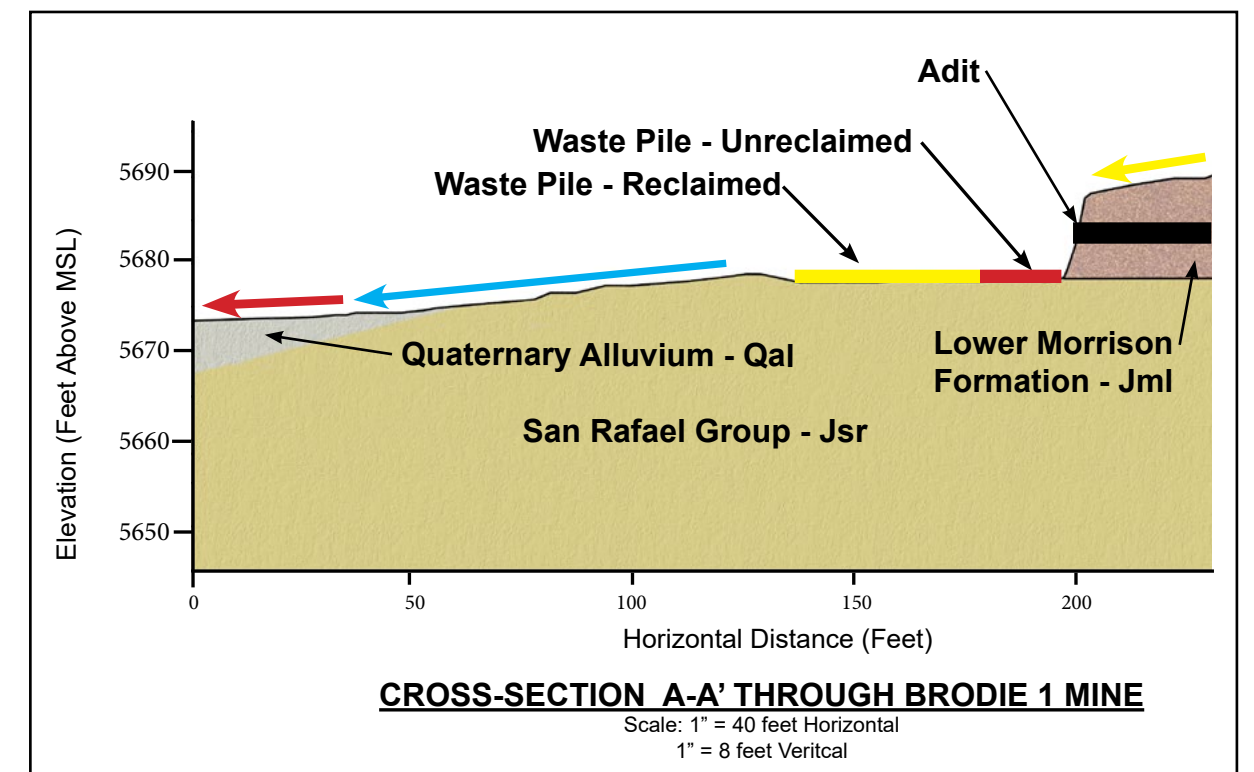
⁶ Potential exposures include inhalation of ambient air and air in burrows and underground mines. The ecological risk evaluation does not include evaluation of the inhalation pathway.

⁷ The ecological risk evaluation does not include evaluation of direct contact with or ingestion of surface water.

Figure 11. Brodie 1 Mine and Tse Tah West Wash Conceptual Site Model Wire Diagram



BRODIE 1 MINE TRANSPORT PATHWAY MODEL



Transport Pathways

- Background Source Erosion
- Waste Rock Erosion
- Waste Deposition, Erosion and Redeposition

Site Features

- Portals
- Waste Pile - Reclaimed
- Waste Pile - Unreclaimed
- Borehole
- Burial Cell
- ↖ Location of Typical Cross-Section
- Geology Contact Line

Prepared for: U.S. EPA Region 9

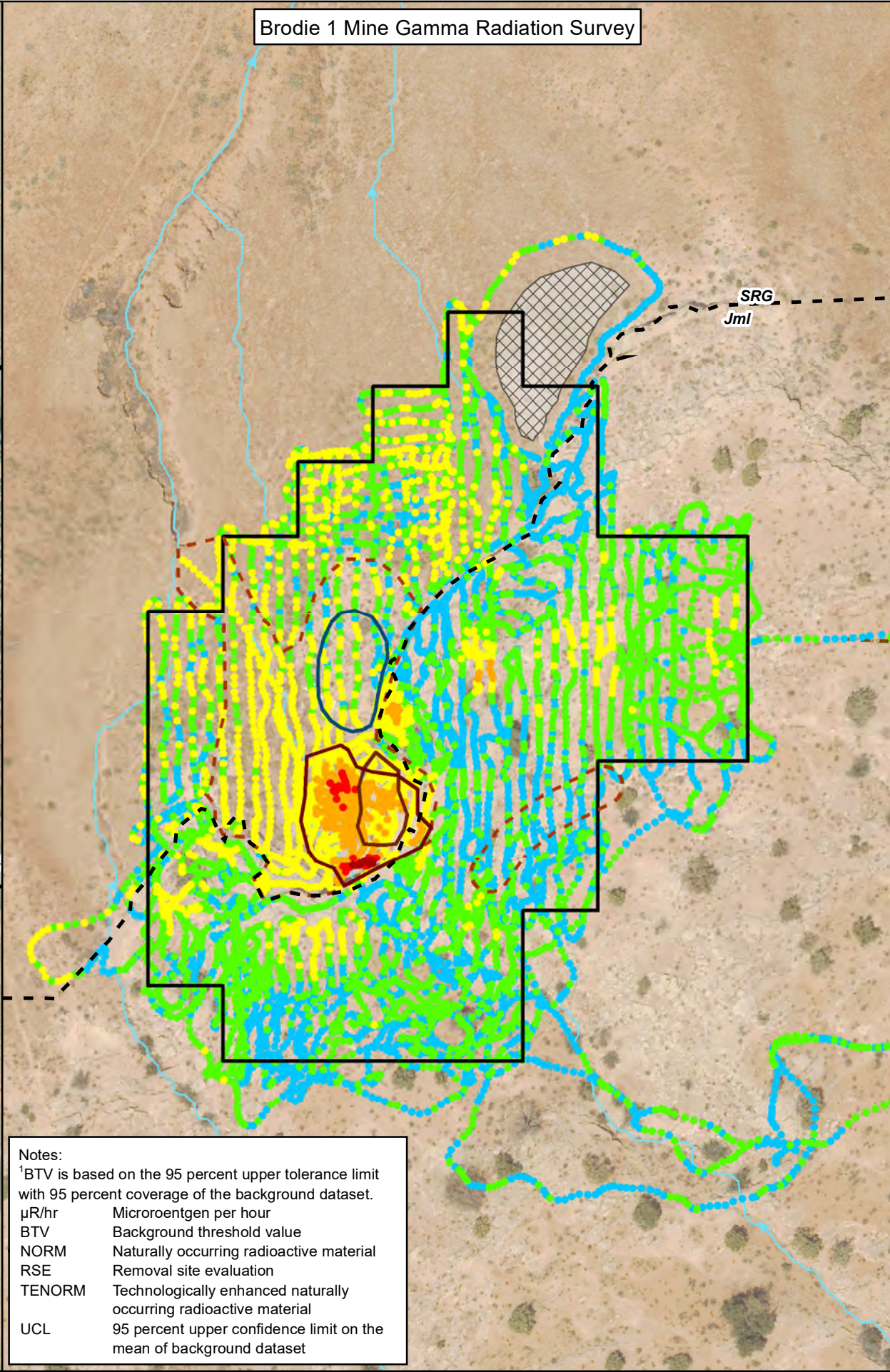
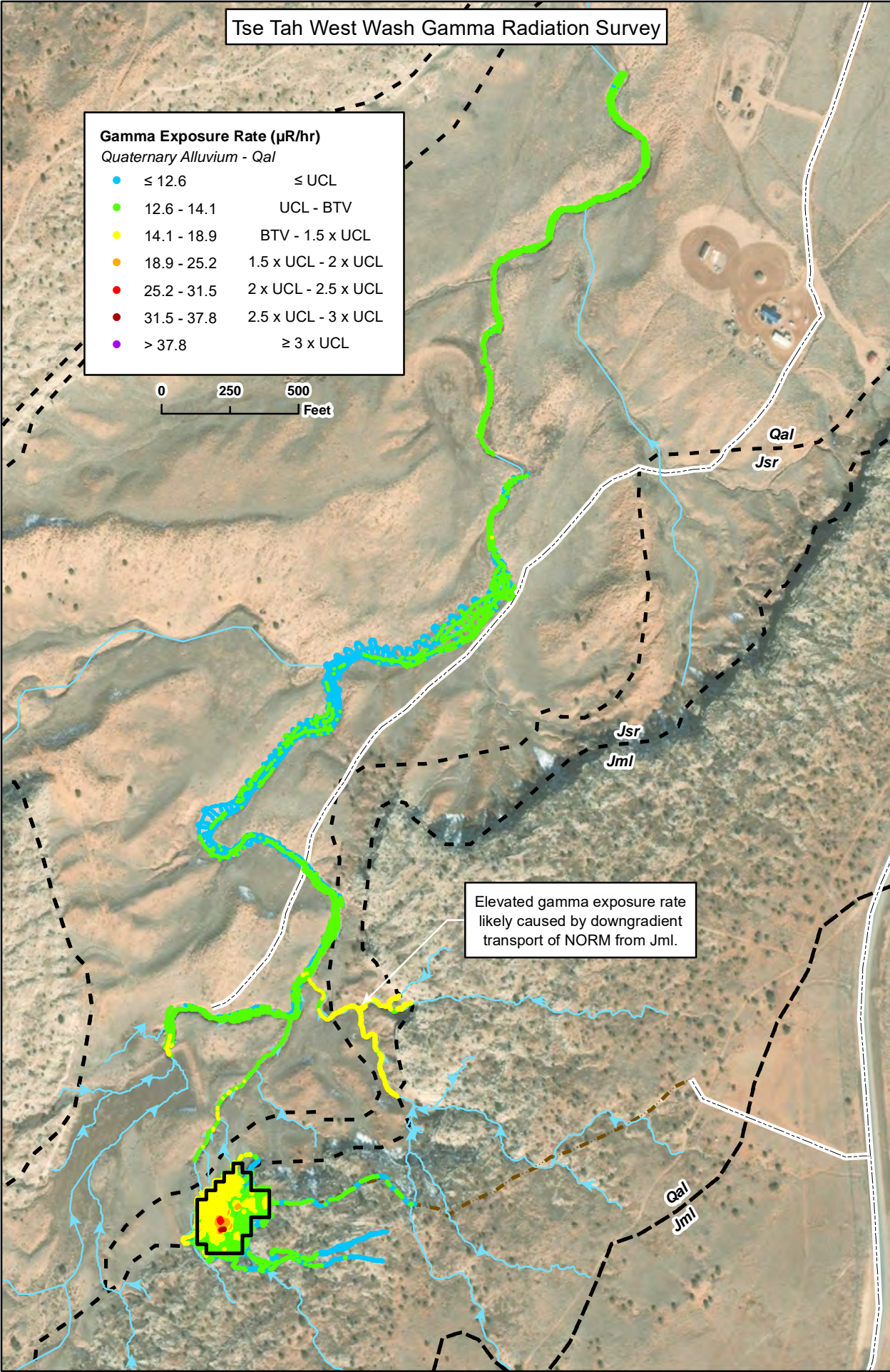


Prepared by:





**BRODIE 1 MINE
TRANSPORT PATHWAYS**

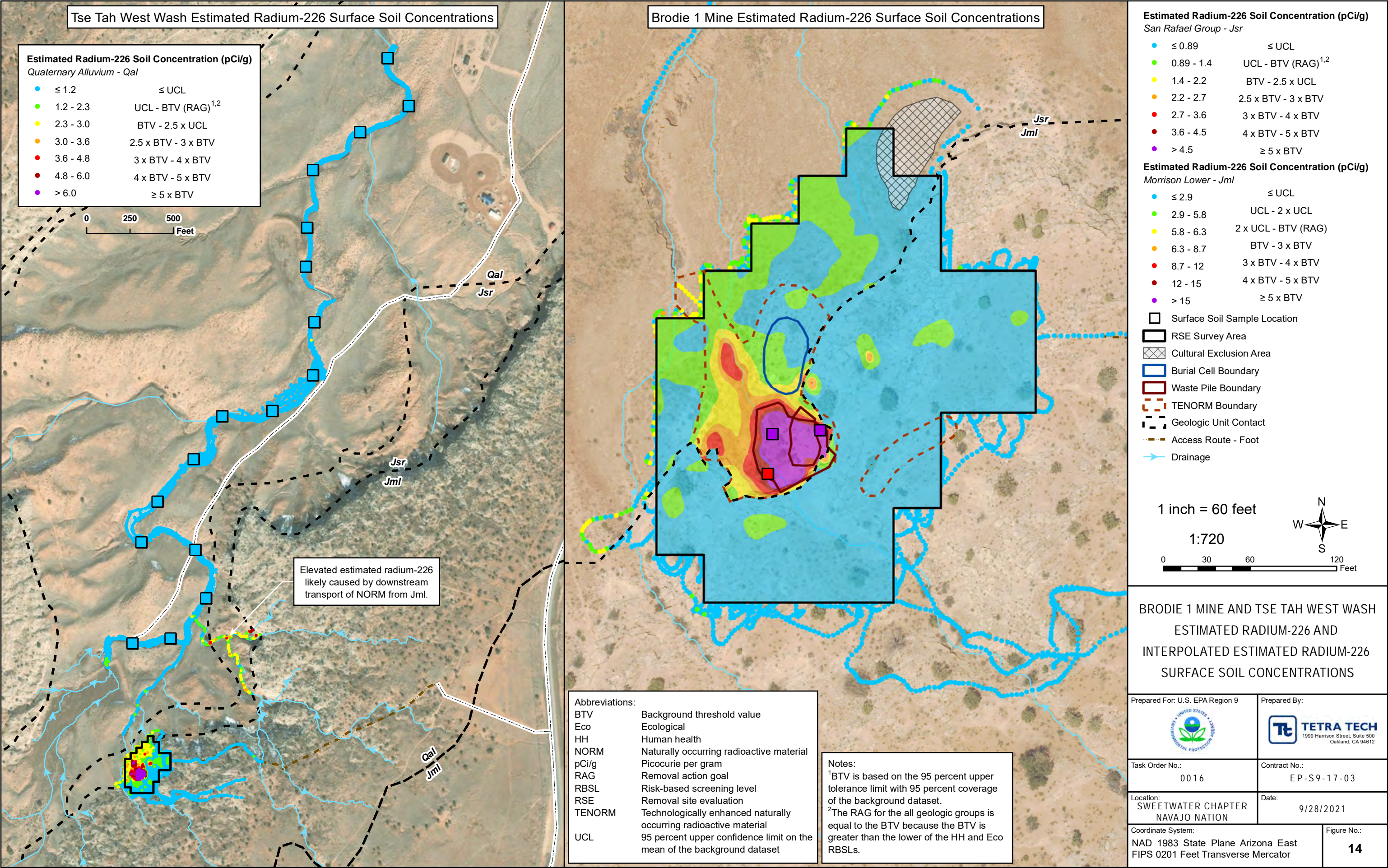
Task Order No.:	Contract No.:	Figure No.:
0016	EP-S9-17-03	
Location.:	Date:	12
NAVAJO NATION	9/09/2021	



Notes:
¹BTV is based on the 95 percent upper tolerance limit with 95 percent coverage of the background dataset.
µR/hr Microrentgen per hour
BTV Background threshold value
NORM Naturally occurring radioactive material
RSE Removal site evaluation
TENORM Technologically enhanced naturally occurring radioactive material
UCL 95 percent upper confidence limit on the mean of background dataset

BRODIE 1 MINE AND TSE TAH WEST WASH GAMMA RADIATION SURVEY

Prepared For: U.S. EPA Region 9	Prepared By:
	 TETRA TECH 1999 Harrison Street, Suite 500 Oakland, CA 94612
Task Order No.: 0016	Contract No.: EP-S9-17-03
Location: SWEETWATER CHAPTER NAVAJO NATION	Date: 9/9/2021
Coordinate System: NAD 1983 State Plane Arizona East FIPS 0201 Feet Transverse Mercator	Figure No.: 13



Screening Levels	Arsenic (mg/kg)	Uranium (mg/kg)	Vanadium (mg/kg)
BTV	2.1	0.90	9.7
HH RBSL	0.31	0.92	27
Eco RBSL	31	250	9.5

Sample ID ⁴	Sample Depth (in)	Arsenic (mg/kg)	Uranium (mg/kg)	Vanadium (mg/kg)
M1X17	0 - 1	1.8 QU	0.08 QU	<u>28</u>
M1X18	0 - 1	1.8 QU	0.08 QU	<u>20</u>

Notes:

¹Results within the TENORM boundary are presented.

²BTV is based on the 95 percent upper tolerance limit with 95 percent coverage of the background dataset.

³Soil sample result for either arsenic (As), selenium (Se), uranium (U), or vanadium (V) exceeds either the HH or Eco RBSL and the BTV.

⁴Metals results are provided for samples that are located outside the area predicted to have radium-226 concentrations exceeding the BTV.

Bold values indicate the result exceeds at least one RBSL (HH or Eco). **Bold underlined** values indicate the result exceeds at least one RBSL and the BTV.

bgs

Below ground surface

BTV

Background threshold value

Eco

Ecological

HH

Human health

in

Inch

Jml

Morrison formation lower

Jsr

San Rafael Group

mg/kg

Milligram per kilogram

QU

Instrumental non-detect result

RBSL

Risk-based screening level

RSE

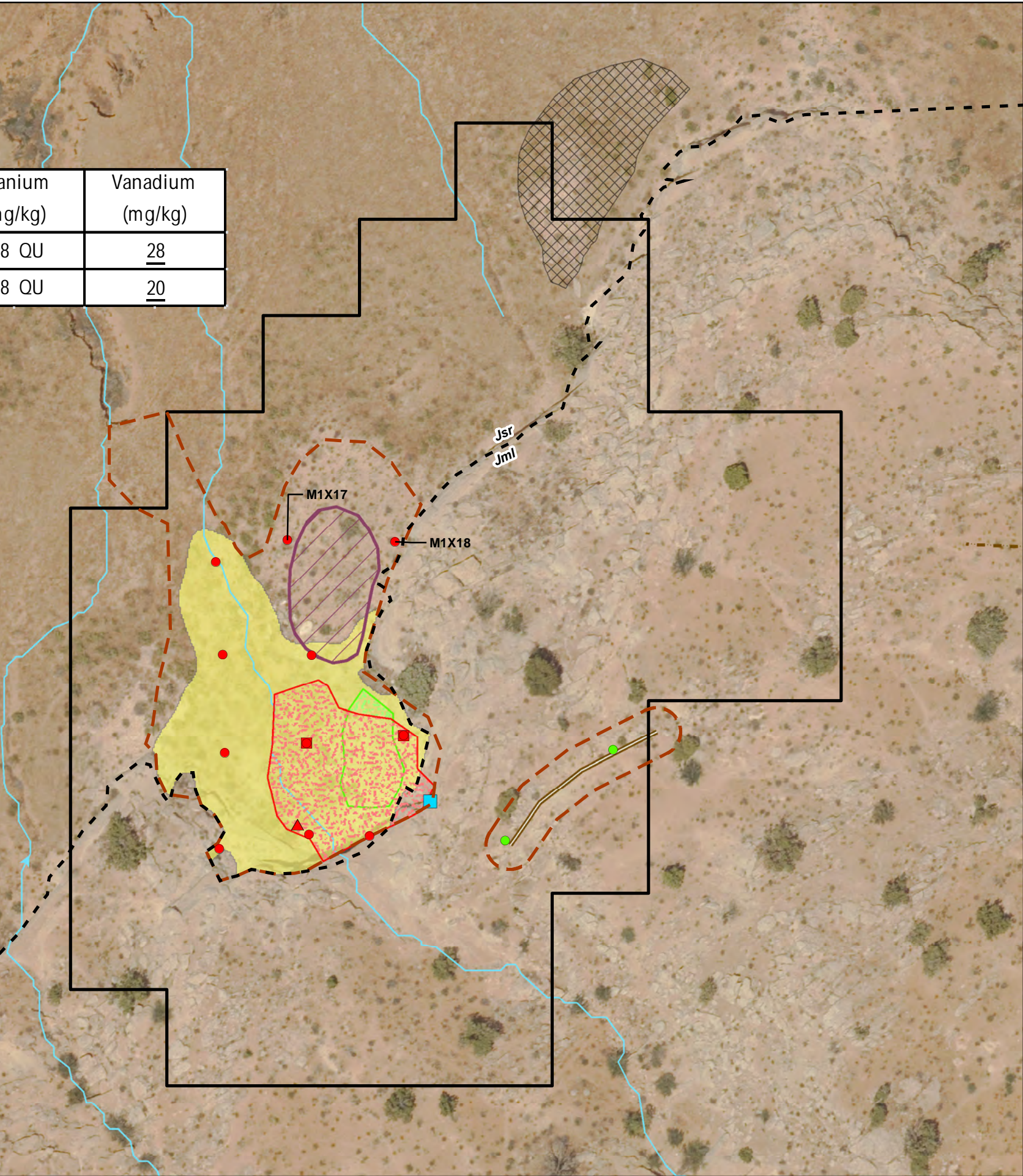
Removal site evaluation

TENORM

Technologically enhanced naturally occurring radioactive material

XRF

X-ray fluorescence



Metals RBSL and BTV Exceedance in Soil Sample^{1,2}

● Exceeds for As, Se, U, or V³

● Does Not Exceed for As, Se, U, or V

Soil Sample Type

○ In Situ XRF Measurement (0-1 inches bgs)

□ XRF Confirmation Soil Sample (0-3 inches bgs)

△ Surface Soil Sample (0-6 inches bgs)

Extent of Interpolated Radium-226 Exceeding BTV

RSE Survey Area

TENORM Boundary

Geologic Unit Contact

Cultural Exclusion Area

Site Features

Closed Portal

Berm

Burial Cell

Waste Pile - Reclaimed

Waste Pile - Unreclaimed

Drainage

1 inch = 40 feet

1:480

0

20

40

80

Feet



N

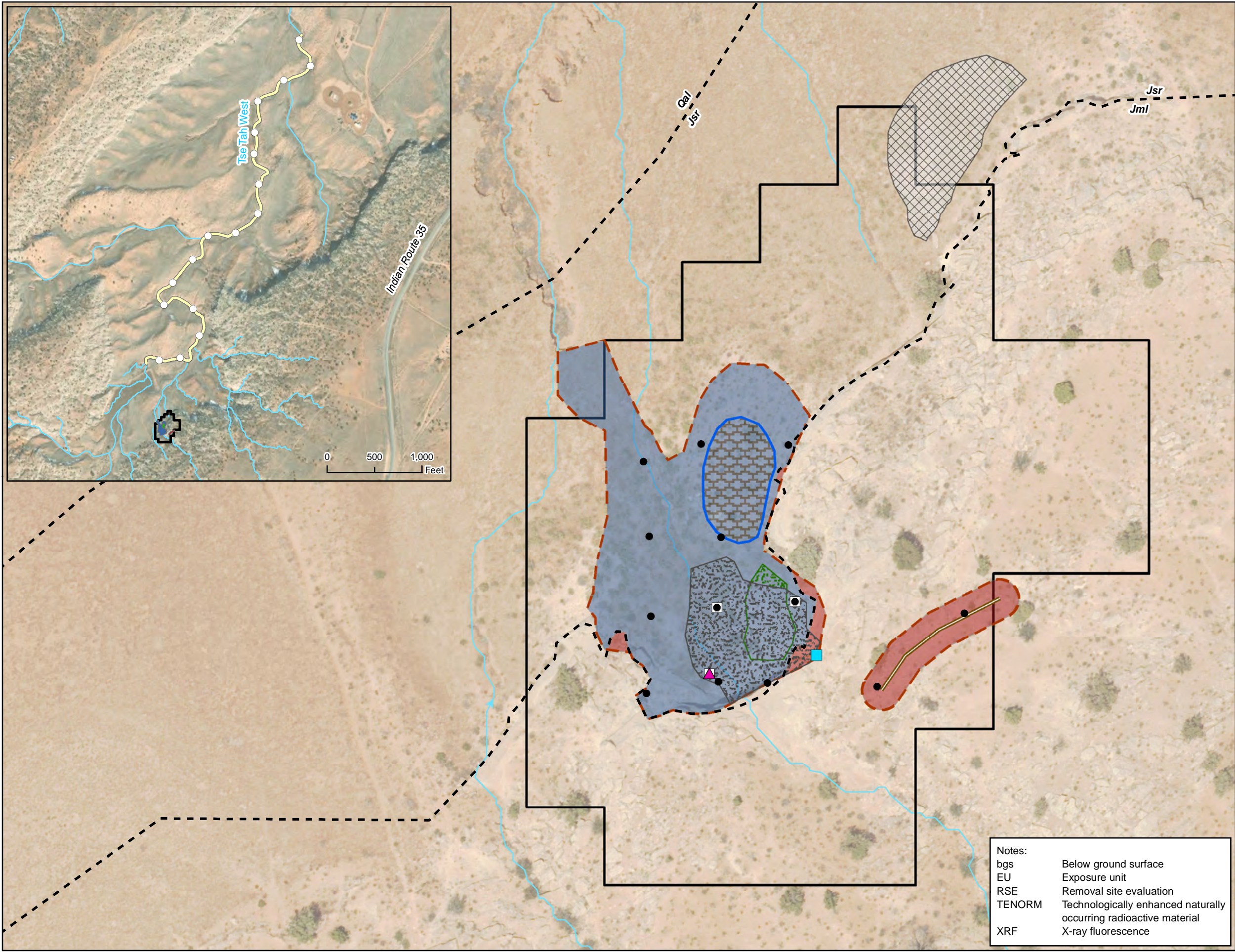
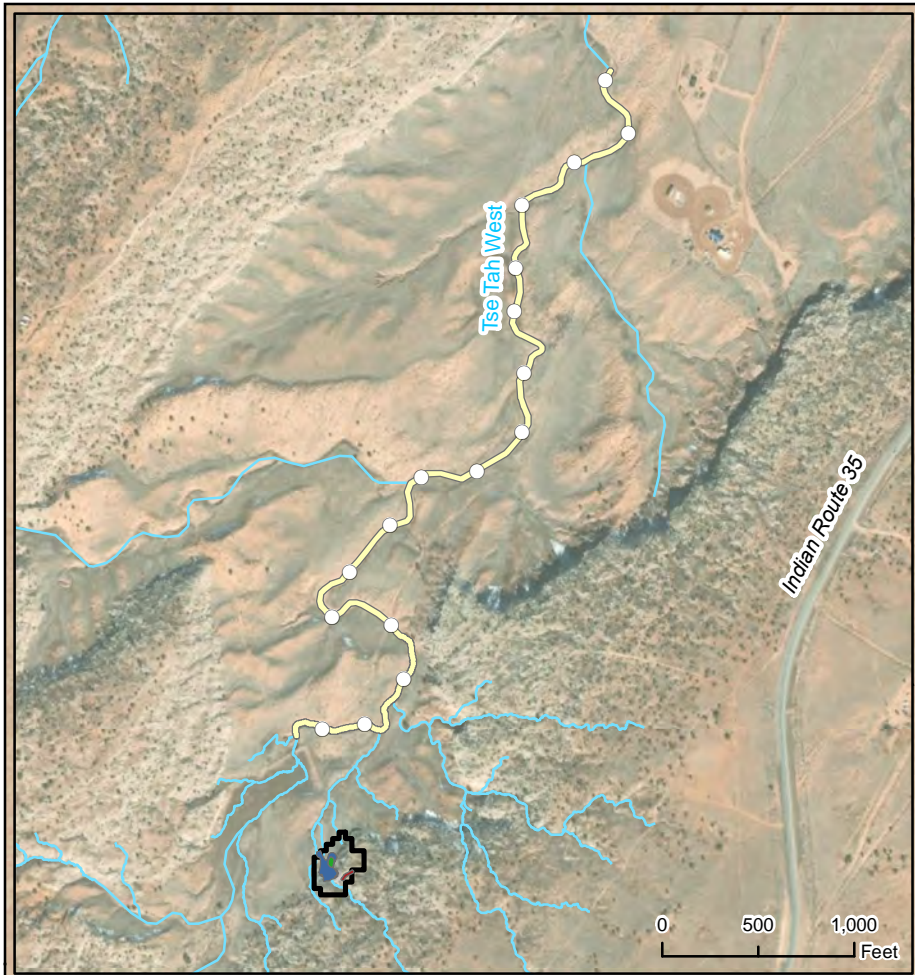
E

S

W

BRODIE 1 MINE
METALS DISTRIBUTION
IN SURFACE SOIL

Prepared For: U.S. EPA Region 9	Prepared By:
	 TETRA TECH 1999 Harrison Street, Suite 500 Oakland, CA 94612
Task Order No.: 0016	Contract No.: EP-S9-17-03
Location: SWEETWATER CHAPTER NAVAJO NATION	Date: 9/24/2021
Coordinate System: NAD 1983 State Plane Arizona East FIPS 0201 Feet Transverse Mercator	Figure No.: 15



Exposure Units

- EU 1 - Full-Time Residential San Rafael Group - Jsr
- EU 2 - Full-Time Residential Lower Morrison Formation - Jml
- EU 3 - Tse Tah West Drainage Quaternary Alluvium - Qal
- EU 4 - Burial Cell 41 (Subsurface Only) San Rafael Group - Jsr

Soil Sample Locations

- In Situ XRF Measurement (0-1 inch bgs)
- Surface Soil Samples (0-12 inches bgs) (includes all lab samples with bottom depth ≤ 12 inches)
- Subsurface Soil Samples (below 12 inches bgs) (includes all lab samples with bottom depth > 12 inches)
- Sediment Sample (0-12 inches bgs)

Site Features

- Closed Portal
- Berm
- Cultural Exclusion Area
- Burial Cell
- Waste Pile - Reclaimed
- Waste Pile - Unreclaimed
- Drainage

Legend

- RSE Survey Boundary
- TENORM Boundary
- Geologic Unit Contact

1 inch = 40 feet



1:480

0 20 40 80 Feet

W N E S

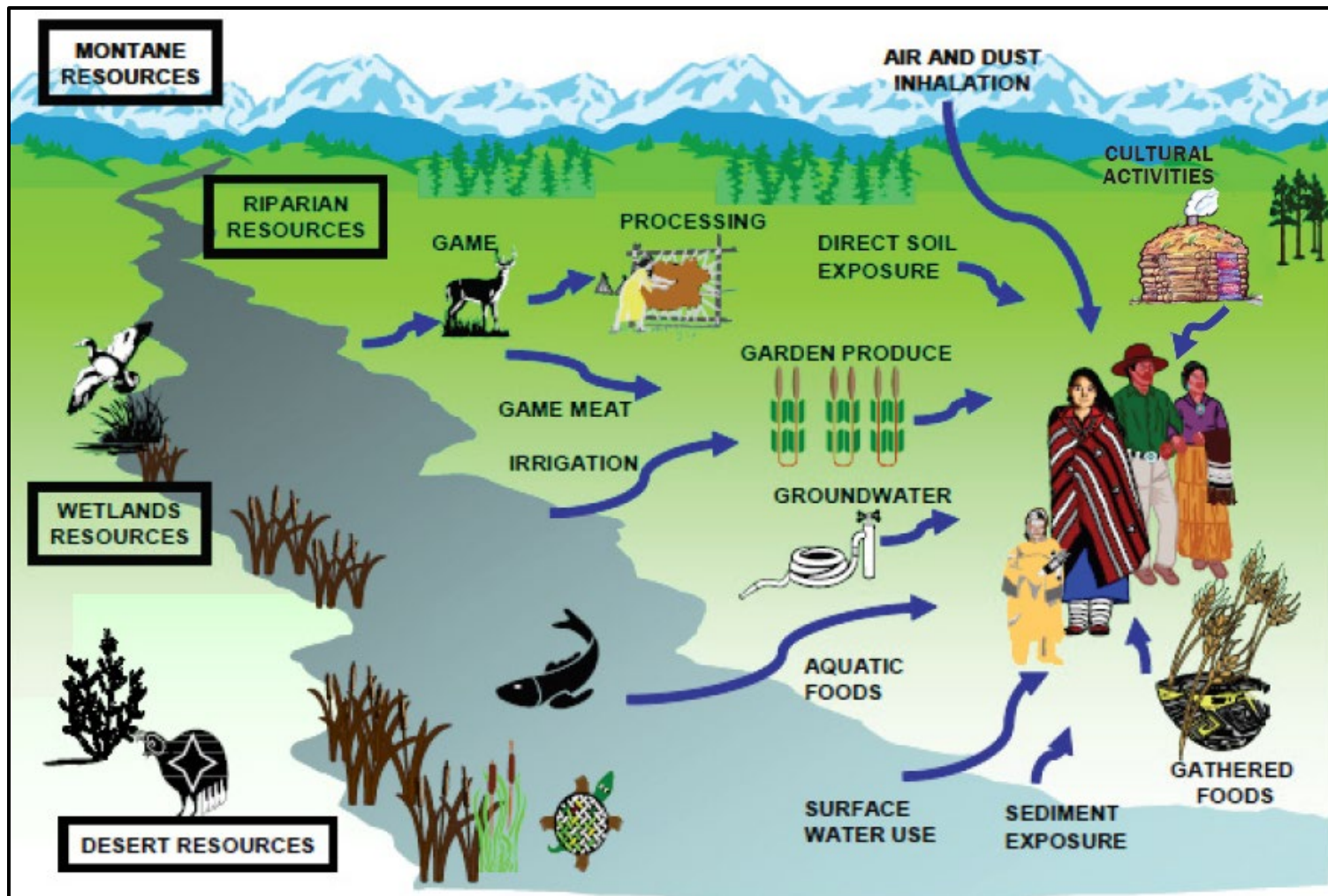
BRODIE 1 MINE

EXPOSURE UNITS

Prepared For: U.S. EPA Region 9	Prepared By:
	 TETRA TECH 1999 Harrison Street, Suite 500 Oakland, CA 94612
Task Order No.: 0016	Contract No.: EP-S9-17-03
Location: SWEETWATER CHAPTER NAVAJO NATION	Date: 9/27/2021
Coordinate System: NAD 1983 State Plane Arizona East FIPS 0201 Feet Transverse Mercator	Figure No.: 16

Notes:

bgs	Below ground surface
EU	Exposure unit
RSE	Removal site evaluation
TENORM	Technologically enhanced naturally occurring radioactive material
XRF	X-ray fluorescence

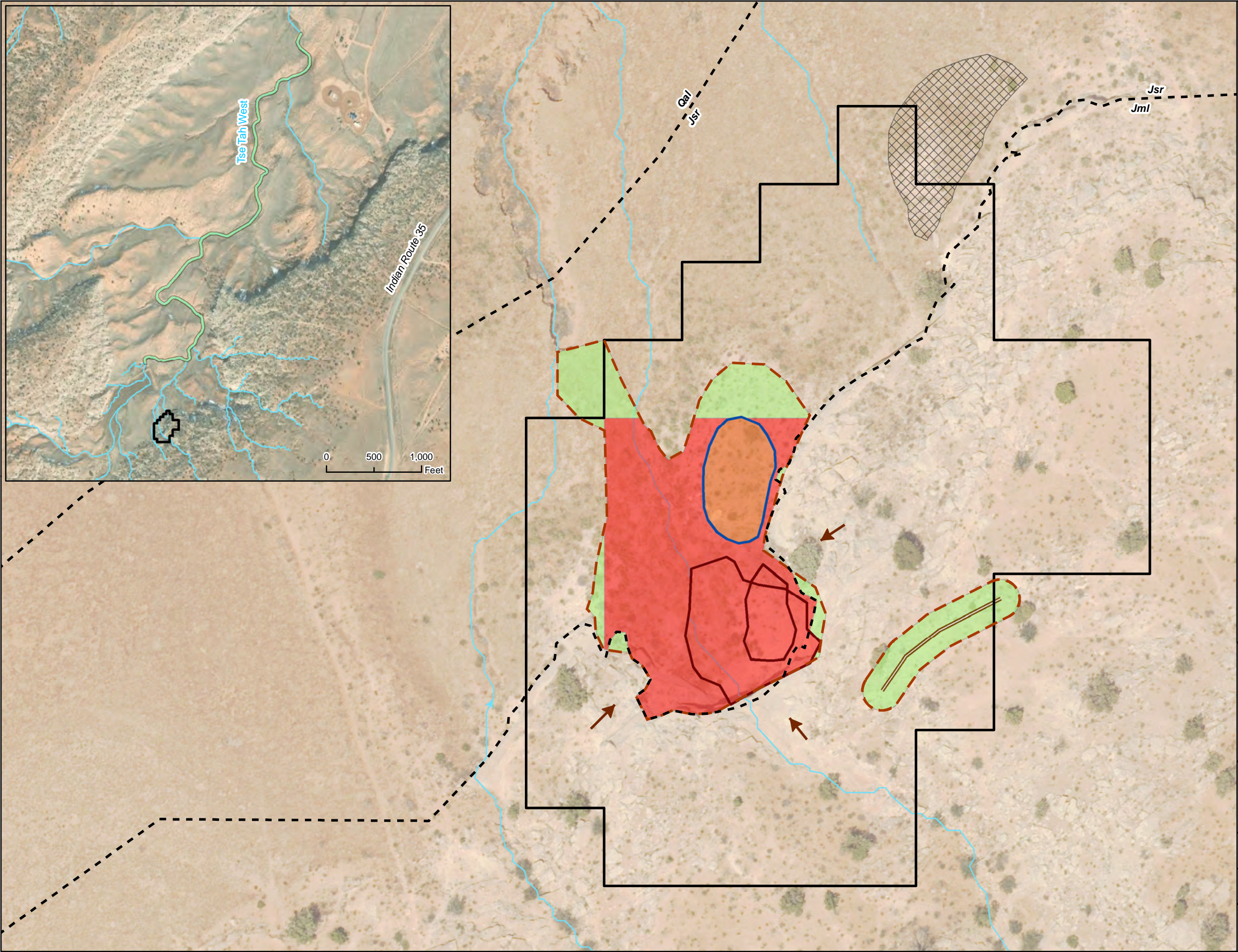
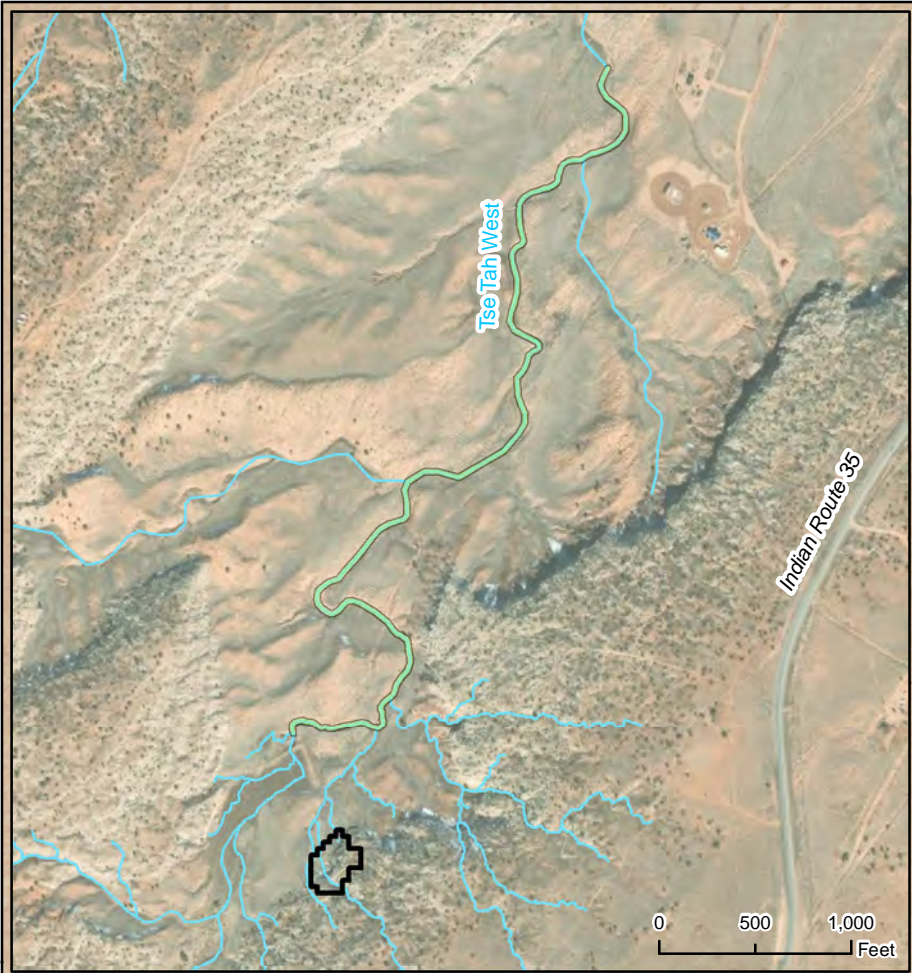


Notes:

Some exposure pathways depicted above are not included in the exposure assessment. See the conceptual site model wire diagram (Figure 11) for a description of the included pathways.

Adapted from B.L. Harper, A.K. Harding, T. Waterhous, and S.G. Harris. 2007. "Traditional Tribal Subsistence Exposure Scenario and Risk Assessment Guidance Manual." Oregon State University. Corvallis, Oregon. August.

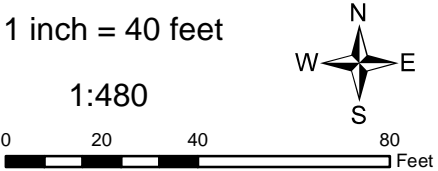
Figure 17. Other Potential Diné Lifeways Exposure Pathways





Proposed Removal Action Extent

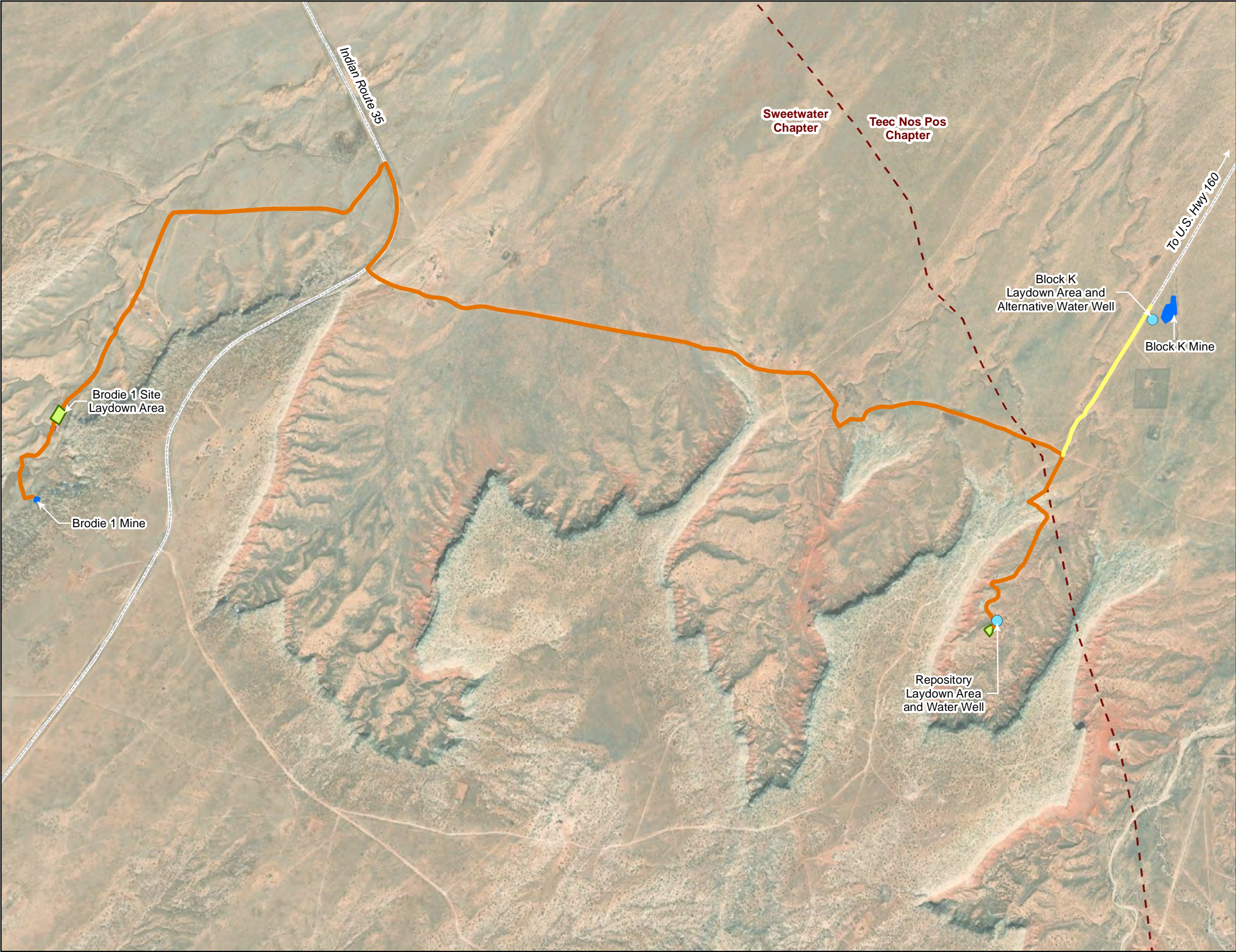
- Excavation
- Burial Cell
- No Cleanup
- Berm
- Slope_Direction
- Drainage
- RSE Survey Boundary
- Burial Cell Boundary
- Waste Pile Boundary
- TENORM Boundary
- Geologic Unit Contact
- Cultural Exclusion Area

Notes:
Jml Morrison formation lower
Qal Quaternary alluvium
Jsr San Rafael Group
RSE Removal site evaluation
TENORM Technologically enhanced naturally occurring radioactive material



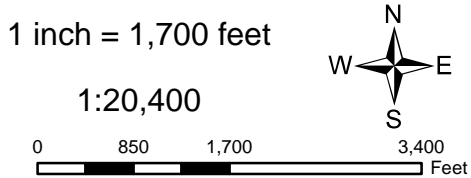
**BRODIE 1 MINE
PROPOSED REMOVAL ACTION EXTENT**

Prepared For: U.S. EPA Region 9 	Prepared By:  TETRA TECH 1999 Harrison Street, Suite 500 Oakland, CA 94612
Task Order No.: 0016	Contract No.: EP-S9-17-03
Location: SWEETWATER CHAPTER NAVAJO NATION	Date: 9/24/2021
Coordinate System: NAD 1983 State Plane Arizona East FIPS 0201 Feet Transverse Mercator	Figure No.: 18



- Proposed Construction Water Well Placement
- Haul and/or Water Access Route (Alternatives 2-5)
- Route to Alternative Water Source
- Proposed Laydown Area
- Community Road
- Navajo Nation Chapter Boundary
- AUM Site

Note:
AUM Abandoned uranium



ALTERNATIVES 2 TO 5 HAUL ROAD, LAYDOWN AREA, AND WATER SOURCE

Prepared For: U.S. EPA Region 9



Prepared By:





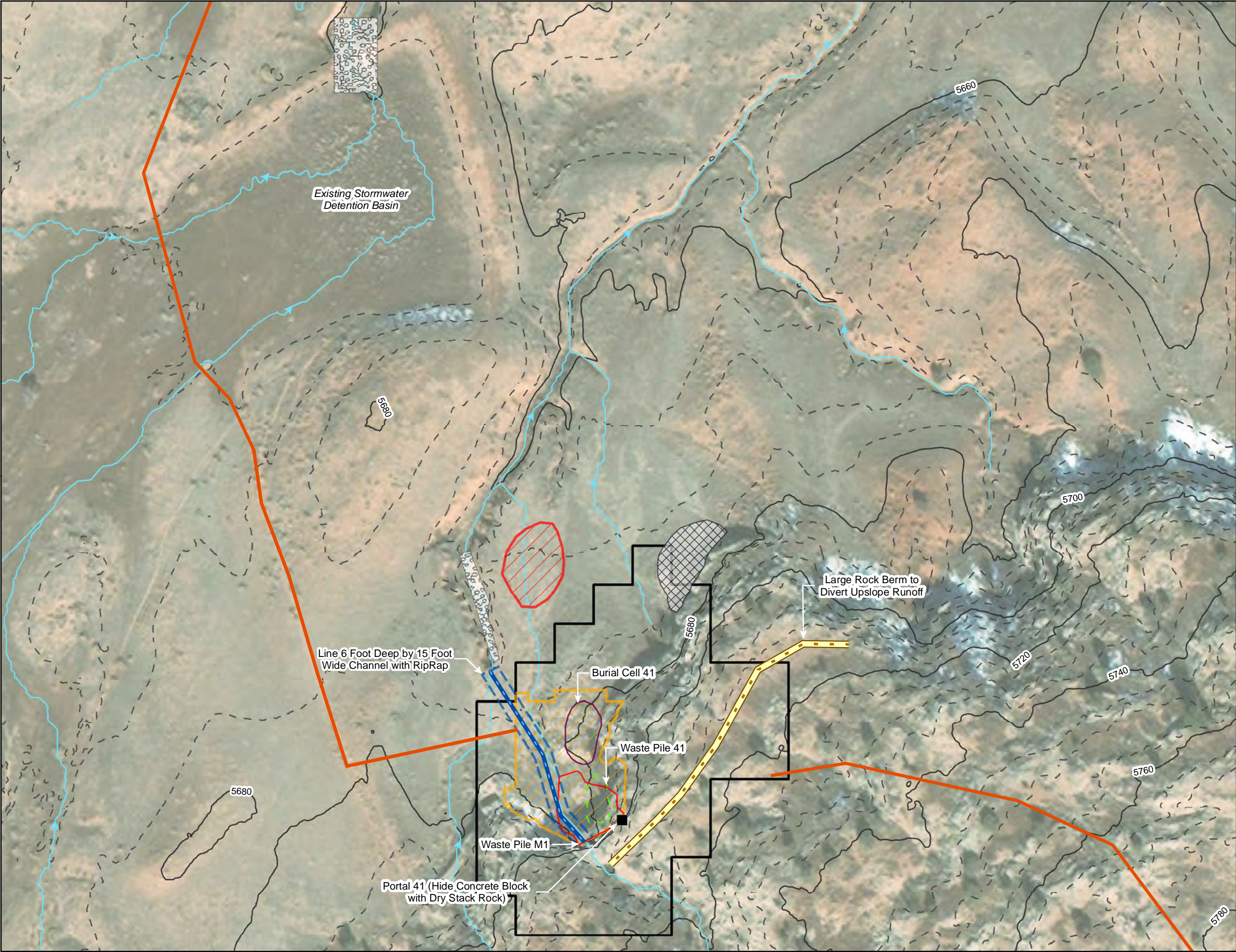
Task Order No.: 0016	Contract No.: EP-S9-17-03
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Location: NAVAJO NATION	Date: 9/24/2021
----------------------------	--------------------

Coordinate System: NAD 1983 State Plane New Mexico West FIPS 3003 Feet Transverse	Figure No.: 19
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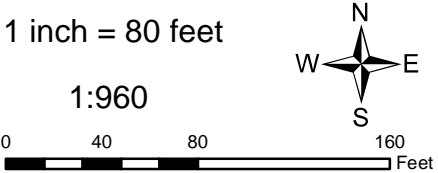


<div><div><div><div></div><div>Existing Access Road (Widening and Grading as Necessary)</div></div><div><div></div><div>New Access Road Construction (Cut and Fill as Needed)</div></div><div><div></div><div>Community Road</div></div><div><div></div><div>Proposed Laydown Yard</div></div><div><div></div><div>Rock Lined Drainage Crossing</div></div><div><div></div><div>Soil Borrow Area (as Needed)</div></div><div><div></div><div>RSE Survey Area</div></div></div><div><div>Notes:</div><div>AUMAbandoned uranium mine</div><div>RSERemoval site evaluation</div></div></div>	<div>Prepared for: U.S. EPA Region 9</div> <div></div>	ACCESS ROAD CONSTRUCTION		
	<div>Prepared By:</div> <div> TETRA TECH 1999 Harrison Street, Suite 500 Oakland, CA 94612</div>	<div>Task Order No.:</div> <div>0016</div>	<div>Contract No.:</div> <div>EP-S9-17-03</div>	<div>Figure No.:</div> <div>20</div>
		<div>Location:</div> <div>NAVAJO NATION</div>	<div>Date:</div> <div>9/24/2021</div>	
		<div>Coordinate System:</div> <div>NAD 1983 State Plane Arizona East FIPS 0201 Feet</div>		



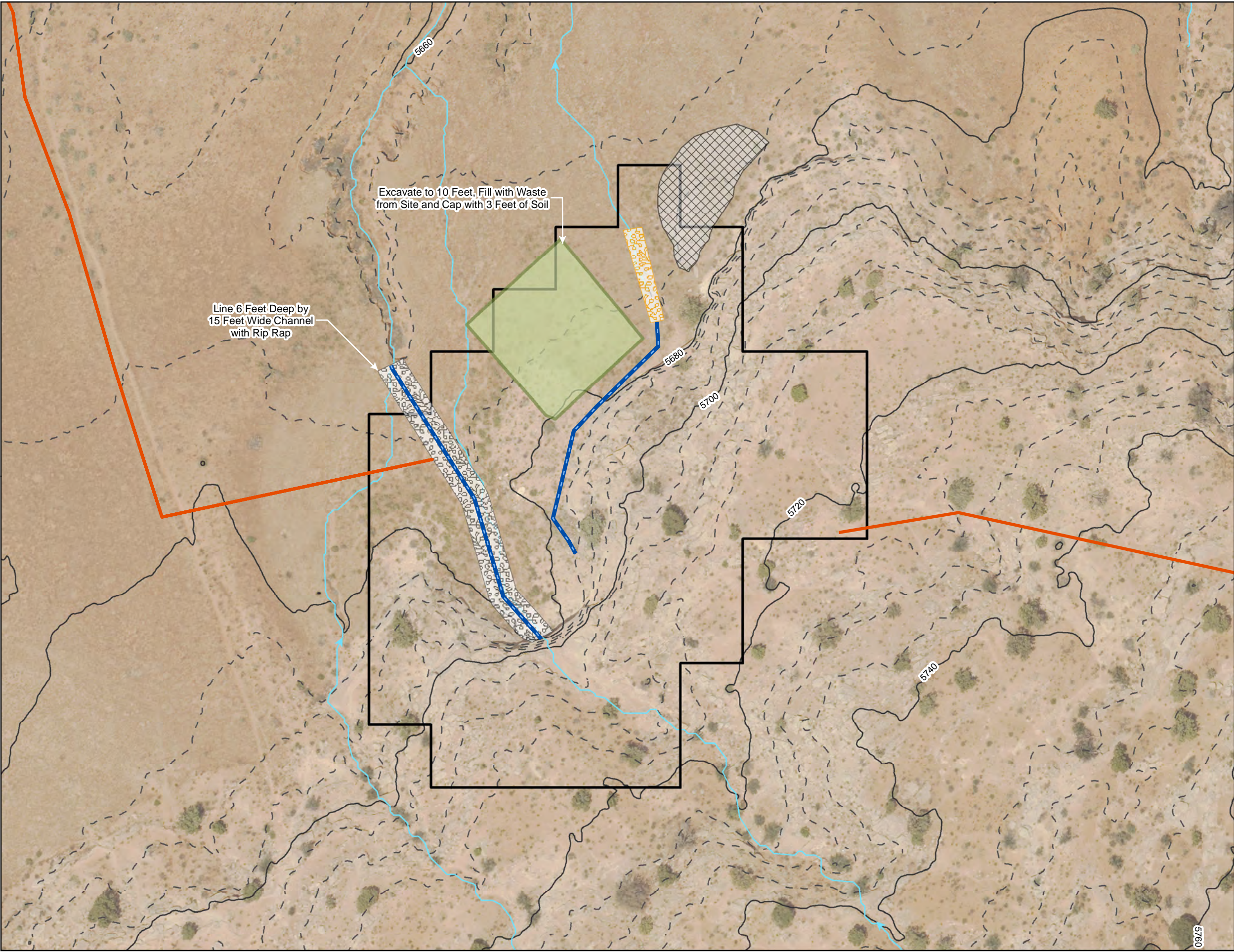
- Construction Disturbance Area (Backfill, Contour Grade Toward Channel, Erosion Control Blanket on Slopes, Revegetate)
- Temporary Waste Stockpile (Contour Grade and Revegetate)
- Rip Rap at Mine Drainage Channel and Stormwater Detention Basin Outfall
- Rip Rap-Lined Drainage Channel
- RSE Survey Area
- Rock Berm
- Drainage Channel
- Access Road from Indian Route 35
- Runoff Pathway
- 20-Foot Contour
- 5-Foot Contour
- Site Features**
 - Closed Portal
 - Cultural Exclusion Area
 - Burial Cell
 - Waste Pile - Reclaimed
 - Waste Pile - Unreclaimed

Note:
RSE Removal site evaluation



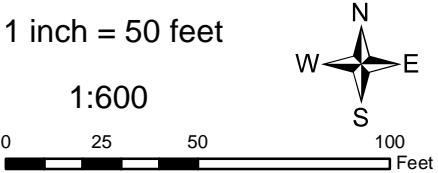
PROPOSED SURFICIAL
RESTORATION ACTIVITES

Prepared For: U.S. EPA Region 9	Prepared By:
	 TETRA TECH 1999 Harrison Street, Suite 500 Oakland, CA 94612
Task Order No.: 0016	Contract No.: EP-S9-17-03
Location: SWEETWATER CHAPTER NAVAJO NATION	Date: 9/24/2021
Coordinate System: NAD 1983 State Plane Arizona East FIPS 0201 Feet Transverse Mercator	Figure No.: 22





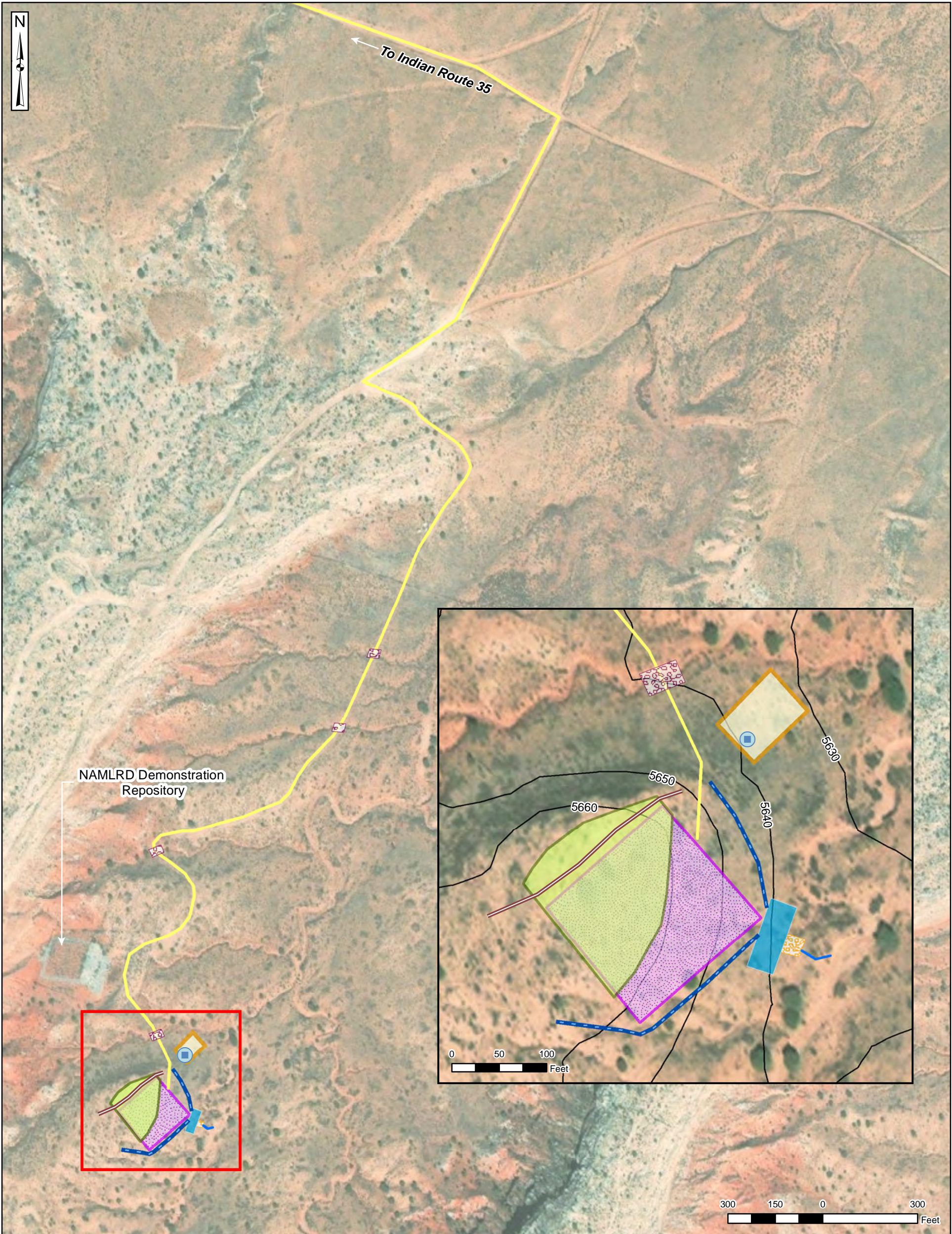
- Burial Cell with Evapotranspiration Cap (Stabilized with biodegradeable mat and coir logs)
- Rip Rap-Lined Drainage Channel
- Rock Outfall
- Drainage Channel
- Access Road from Indian Route 35
- RSE Survey Area
- Cultural Exclusion Area
- Runoff Pathway
- 20-Foot Contour
- 5-Foot Contour

Note:
RSE Removal site evaluation






ALTERNATIVE 2 — BURIAL CELL
LOCATION AND FEATURES

Prepared For: U.S. EPA Region 9	Prepared By:
	 TETRA TECH 1999 Harrison Street, Suite 500 Oakland, CA 94612
Task Order No.: 0016	Contract No.: EP-S9-17-03
Location: SWEETWATER CHAPTER NAVAJO NATION	Date: 9/29/2021
Coordinate System: NAD 1983 State Plane Arizona East FIPS 0201 Feet Transverse Mercator	Figure No.: 23



<div><div><div><div><div></div><div>Proposed Regional Repository</div></div><div><div></div><div>Proposed Repository Laydown Yard</div></div><div><div></div><div>Soil Borrow Area</div></div><div><div></div><div>Proposed Sediment/Water Detention Basin</div></div><div><div></div><div>Rock Outfall</div></div><div><div></div><div>Rock-Lined Drainage Crossing</div></div><div><div></div><div>Proposed Construction Water Well Placement</div></div></div><div><div><div></div><div>Haul Road from Indian Route 35</div></div><div><div></div><div>Rock-Faced Berm</div></div><div><div></div><div>Rock-Lined Drainage Channel</div></div><div><div></div><div>Exsisting Drainage Swale</div></div><div><div></div><div>10-Foot Contour</div></div></div></div><div>Note: NAMLRD Navajo Abandoned Mine Lands Reclamation Department</div></div>		<div>Prepared for: U.S. EPA Region 9</div> <div><div><div></div><div>UNITED STATES ENVIRONMENTAL PROTECTION AGENCY</div></div></div> <div>Prepared By:</div> <div><div><div></div><div>TETRA TECH</div><div>1999 Harrison Street, Suite 500 Oakland, CA 94612</div></div></div>		<div>ALTERNATIVE 3 — ON-NAVAJO NATION REGIONAL REPOSITORY LOCATION, FEATURES, AND HAUL ROUTE</div>		
		Task Order No.: 0016		Contract No.: EP-S9-17-03		Figure No.: 24
		Location: SWEETWATER CHAPTER NAVAJO NATION		Date: 9/29/2021		
		Coordinate System: NAD 1983 State Plane Arizona East FIPS 0201 Feet Transverse Mercator				



-  Brodie 1 Mine
-  Populated Place
-  Proposed Haul Route

0 4 8 Miles



Prepared for: U.S. EPA Region 9



Prepared By:



ALTERNATIVE 4 — OFF-NAVAJO NATION DISPOSAL AT WHITE MESA MILL HAUL ROUTE

Task Order No.:

0016

Contract No.:

EP-S9-17-03

Figure No.:

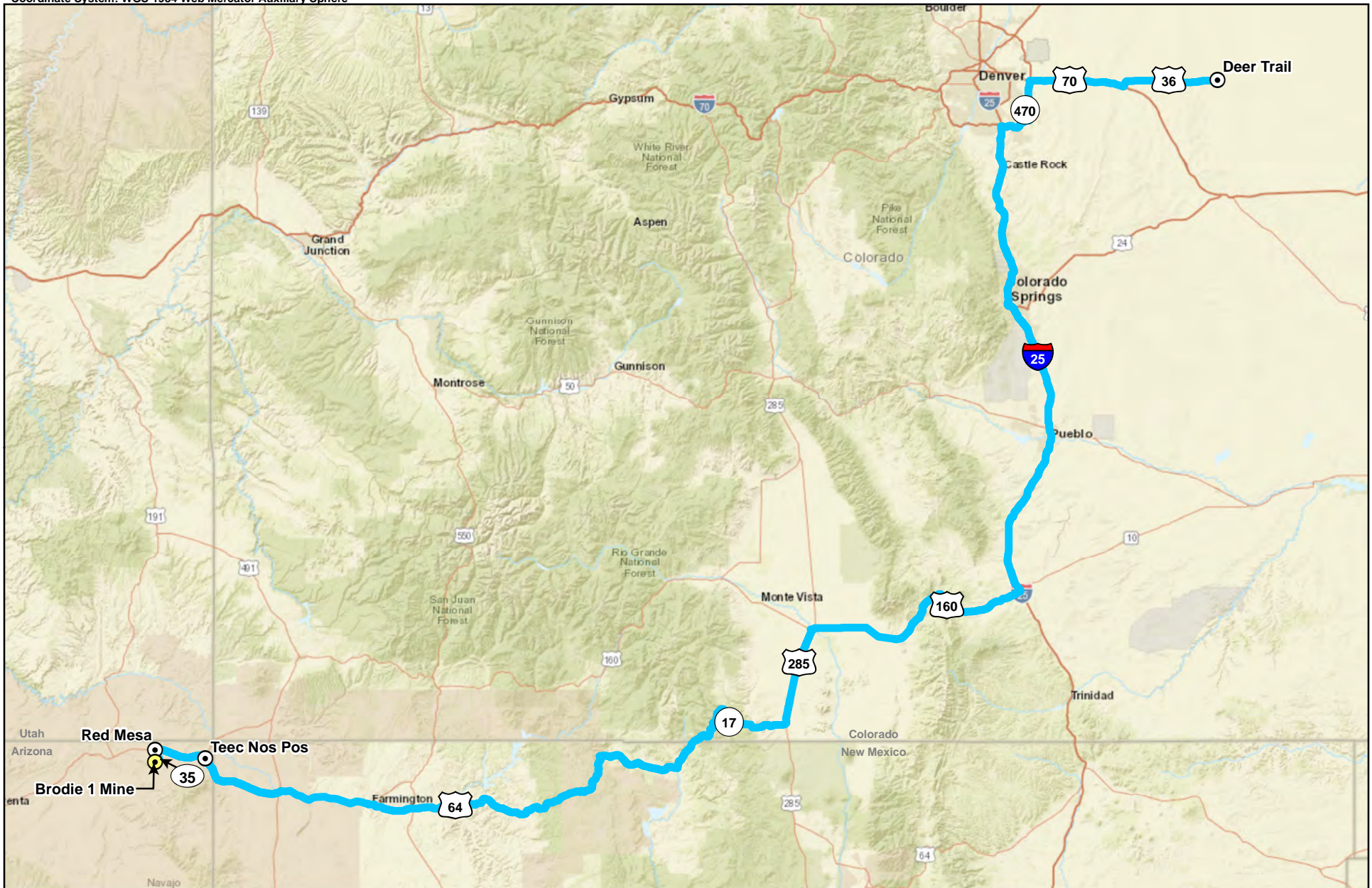
25

Location:

NAVAJO NATION

Date:

9/29/2021



- Brodie 1 Mine
- Populated Place
- Proposed Haul Route

Note:
RCRA Resource Conservation and Recovery Act

0 25 50 Miles



Prepared for: U.S. EPA Region 9



Prepared By:



ALTERNATIVE 5 — OFF-NAVAJO NATION DISPOSAL AT CLEAN HARBORS RCRA SUBTITLE C HAZARDOUS WASTE DISPOSAL FACILITY HAUL ROUTE

Task Order No.:

0016

Contract No.:

EP-S9-17-03

Figure No.:

26

Location:

NAVAJO NATION

Date:

9/29/2021

TABLES

Table 1. Mine Features and Dimensions at Brodie 1 Mine

Feature	Reclamation Status	Reclamation Description	Dimensions
Portal 41	Reclaimed	Excavated; stabilized; and closed with 76-square-foot cement block bulkhead using 5 cubic yards of concrete-filled reinforced masonry	9 feet by 7 feet
Waste Pile 41	Unreclaimed	Approximately 250 cubic yards of mine waste partially removed and placed in Burial Cell 41; encompassed by Waste Pile M1	0.015 acre
Waste Pile M1	Unreclaimed	None; field mapped during the RSE investigation	0.05 acre
Burial Cell 41	Reclamation Feature	Approximately 210 cubic yards of material excavated to a depth of approximately 4 feet and stockpiled north of the excavation; waste placed in burial cell with 1.5 feet of cover; waste covered with 150 cubic yards of stockpiled material	0.029 acres 250 cubic yards of waste
Berm 41	Reclamation Feature	Approximately 60 cubic yards of stockpiled material from excavated Burial Cell 41 was used to construct the berm above Portal 41 to divert surface water	60 linear feet

Note:

RSE Removal site evaluation

Table 2. COPC/COPEC Screening of Maximum Detected Concentrations against Risk-Based Screening Levels and Background Values

Evaluation of Soil Samples within the San Rafael Group						
Analyte	Units	Maximum Concentration in Surface Soil (0-12 inches bgs)	Navajo-Specific Human Health RBSL ^a	Ecological RBSL ^b	Background Values - San Rafael Group ^{c,d}	
			Kee'da'whíí tééh (Full-Time Navajo Resident)		UCL95	BTV
Radionuclides ^e						
Radium-226	pCi/g	20	0.11	15	0.89	1.4
Metals						
Arsenic	mg/kg	3.6	0.31	31	1.5	2.2
Selenium	mg/kg	0.48	5.8	1	0.31	0.46
Uranium	mg/kg	460	0.92	250	0.63	0.90
Vanadium	mg/kg	170	27	9.5	6.9	9.7

Evaluation of Soil Samples within the Lower Morrison Formation						
Analyte	Units	Maximum Concentration in Surface Soil (0-12 inches bgs)	Navajo-Specific Human Health RBSL ^a	Ecological RBSL ^b	Background Values - Lower Morrison Formation ^c	
			Kee'da'whíí tééh (Full-Time Navajo Resident)		UCL95	BTV
Radionuclides ^e						
Radium-226	pCi/g	NS	0.11	15	2.9	6.3
Metals						
Arsenic	mg/kg	9.0	0.31	31	5.0	20
Selenium	mg/kg	NS	5.8	1	0.55	1.2
Uranium	mg/kg	4.6	0.92	250	3.6	7.3
Vanadium	mg/kg	ND	27	9.5	7.3	17

Table 2. COPC/COPEC Screening of Maximum Detected Concentrations against Risk-Based Screening Levels and Background Values

Evaluation of Sediment Samples within Quaternary Alluvium						
Analyte	Units	Maximum Concentration in Surface Soil (0-12 inches bgs)	Navajo-Specific Human Health RBSL ^a	Ecological RBSL ^b	Background Values - Quaternary Alluvium ^c	
			Chíí dah wiíh íeezh (Washes and Drainages) Tse Tah West Wash		UCL95	BTV
Radionuclides ^e						
Radium-226	pCi/g	1.0	0.65	15	1.2	2.3
Metals						
Arsenic	mg/kg	1.3	2.7	31	1.5	3.9
Selenium	mg/kg	ND	64	1	0.38	1.0
Uranium	mg/kg	0.70	8.8	250	0.86	1.5
Vanadium	mg/kg	5.5	180	9.5	7.0	11

Notes:

Bolded values indicate the maximum site concentration exceeds the screening level or BTV.

- a The human health RBSLs were calculated using the Navajo risk-based remediation goal calculator (under development). The screening levels were calculated using exposure parameter inputs recommended by the Navajo Nation Environmental Protection Agency and include external radiation exposure, soil ingestion, dermal contact (metals only), soil (or dust) inhalation, consumption of homegrown produce and gathered wild plants, consumption of homegrown animal products (meat, eggs, and milk), and consumption of hunted animals (meat only). The scenarios also include use of plants for medicinal and ceremonial purposes. Screening levels are based on a target cancer risk of three in ten thousand (3E-04) and target noncancer hazard of 1. The exposure scenarios, including input parameters and rationale, are provided in the "Navajo Nation-Wide Risk Assessment Conceptual Site Model and Methodology" (Tetra Tech, Forthcoming). See Table 6 for the full set of human health RBSLs.
- b Ecological RBSLs presented are the minimum LOEC for all applicable feeding guilds. LOECs are based on the Los Alamos National Laboratory ECORISK database low-effect level environmental screening levels (Newport News Nuclear BWXT-Los Alamos, LLC. 2020). See Table 6 for the full set of ecological RBSLs.
- c Background values are UCL95 and UTL-95-95 values from the 2021 Provisional Northern AUM Regional BTVs (Tetra Tech 2021).
- d The San Rafael Group includes the Summerville Formation, Cove Springs sandstone, Bluff sandstone, Entrada sandstone, and Carmel Formation.
- e For radionuclides, uranium-238 is assumed to be in secular equilibrium with its decay chain (that is, all decay chain nuclides present in equal activity concentrations). In this case, the risk from radium-226 and its decay products (that is radium-226 in secular equilibrium) will account for most of the risk from the uranium-238 decay chain. Further information on secular equilibrium is provided in Section 2.4.3.

Table 2. COPC/COPEC Screening of Maximum Detected Concentrations against Risk-Based Screening Levels and Background Values

Notes (Continued):

AUM	Abandoned uranium mine
bgs	Below ground surface
BTV	Background threshold value
COPC	Contaminant of potential concern
COPEC	Contaminant of potential ecological concern
ND	Not detected
NS	Not sampled
LOEC	Lowest observed effects concentration
mg/kg	Milligram per kilogram
pCi/g	Picocurie per gram
RBSL	Risk-based screening level
Tetra Tech	Tetra Tech, Inc.
UCL95	One-sided 95 percent upper confidence limit on the mean
UTL-95-95	95 percent upper tolerance limit with 95 percent coverage

References:

Newport News Nuclear BWXT-Los Alamos, LLC. 2020. "ECORISK Database (Release 4.2)." Document EM2020-0575, Los Alamos, New Mexico. N3B 2020, 701067. November.

Tetra Tech, Inc. (Tetra Tech). 2021. "Technical Memorandum on Regional Background Statistics and Provisional BTVs for the Lukachukai Mountain, Cove Valley, and Tse Tah Regions Using Tronox and Cyprus Amax Data." August 8.

Tetra Tech. Forthcoming. "Navajo Nation-Wide Risk Assessment Conceptual Site Model and Methodology. "

Table 3. Summary Statistics for Surface Soil in the TENORM Boundary

Brodie 1 Mine TENORM Area (0-12 inches bgs) (EUs 1 and 2)												
COPC / COPEC	Units	Detection Frequency	Number of High Nondetect Results ^a	Minimum Concentration (qualifier)	Maximum Concentration (qualifier)	Location of Maximum Concentration	Arithmetic Mean ^b	UCL95 / Distribution ^{c, d}	Exposure Point Concentration			
									Value	Statistic ^e	Method ^f	
Radium-226	pCi/g	18 / 21	0	0.39 J-	20	M1-XS32-01-051218	2.2	6.7 NP	6.7	UCL	(15)	
Arsenic	mg/kg	24 / 32	0	0.59	9.0	M1X38	1.4	2.7 NP	2.7	UCL	(15)	
Selenium	mg/kg	4 / 21	0	0.36 J	0.48 J	M1-SB36-0612-01-091618	0.40	0.45 N	0.45	UCL	(4)	
Uranium	mg/kg	29 / 32	0	0.30	460.0	M1-SB36-0612-01-091618	17	80 NP	80	UCL	(15)	
Vanadium	mg/kg	29 / 32	0	3.0	170	M1-XS31-01-051218	29	64 NP	64	UCL	(15)	

Notes:

a	Number of nondetect results that exceeded the maximum detected concentration. These results were not included in the statistical calculations.					
b	The arithmetic mean for datasets with nondetected results is calculated using the Kaplan-Meier method.					
c	Following USEPA (2002, 2015) guidance, this value may be estimated by a 95, 97.5, or 99 percent UCL depending on the sample size, skewness, and degree of censorship.					
d	Tested using the Shapiro-Wilk W or Lilliefors test for normal and lognormal distributions and the Anderson-Darling and Kolmogorov-Smirnov tests for gamma distributions. A 5 percent level of significance was used in all tests. Distribution tests were conducted only for samples with at least four detected results. Distributions not confirmed as normal (N), lognormal (LN), or gamma (G) were treated as nonparametric (NP) in all statistical calculations.					
e	The EPC is the lesser of the UCL95 and the maximum detected result. The maximum detected result is the default when there are fewer than 10 samples or fewer than four detected results. All methods follow USEPA (2002, 2015).					
f	The statistical methods for selecting the exposure point concentration are as follows (not all are used):					
	(1)	Maximum detected concentration	(8)	95% Gamma Approximate KM-UCL	(15)	95% KM Chebyshev UCL
	(2)	95% Student's t UCL	(9)	95% H-UCL	(16)	97.5% Chebyshev UCL
	(3)	95% Modified-t UCL	(10)	95% H-UCL (KM log)	(17)	97.5% KM Chebyshev UCL
	(4)	95% KM (t) UCL	(11)	95% BCA Bootstrap UCL	(18)	99% Chebyshev UCL
	(5)	95% Adjusted Gamma UCL	(12)	95% Bootstrap-t UCL	(19)	99% KM Chebyshev UCL
	(6)	95% Gamma Adjusted KM-UCL	(13)	95% KM BCA UCL		
	(7)	95% Approximate Gamma UCL	(14)	95% Chebyshev UCL		
BCA	Bias-corrected accelerated bootstrap method		J	Estimated value	NP	Nonparametric distribution
bgs	Below ground surface		J-	Estimated value, biased low	pCi/g	Picocurie per gram
COPC	Contaminant of potential concern		KM	Kaplan-Meier	TENORM	Technologically enhanced naturally occurring
COPEC	Contaminant of potential ecological concern		KM (t)	UCL based upon Kaplan-Meier estimates		radioactive material
EPC	Exposure point concentration			using the Student's t-distribution critical value	UCL	Upper confidence limit of the mean
EU	Exposure unit		LN	Lognormal distribution	UCL95	One-sided 95 percent upper confidence limit
G	Gamma distribution		mg/kg	Milligram per kilogram		on the mean
H-UCL	UCL based upon Land's H-statistic		N	Normal distribution	USEPA	U.S. Environmental Protection Agency

References:

U.S. Environmental Protection Agency (USEPA). 2002. "Calculating Exposure Point Concentrations at Hazardous Waste Sites." OSWER 9285.6-10. Office of Emergency and Remedial Response. December.

USEPA. 2015. "ProUCL Version 5.1 Technical Guide." Prepared by A. Singh and A.K. Singh. EPA/600/R-07/041. October.

Table 4. Exposure Unit Summary of Type, Area, Land Use, Geologic Formation, and Available Samples

Exposure Unit	Land Use / Receptor	Geologic Formation	Type	Area (m ²)	Depth (inches bgs)	XRF In Situ Soil (0-1 inches bgs)	XRF Confirmation Surface Soil (0-3 inches bgs)	Surface Soil (0-6 inches bgs)	Surface Soil (6-12 inches bgs)	Sediment (0-6 inches bgs)	Total Number of Samples
1	Kee'da'whíí tééh (Full-Time Navajo Resident)	San Rafael Group	TENORM	976 ^a	0-12	9	2	1	1	0	13
2	Kee'da'whíí tééh (Full-Time Navajo Resident)	Lower Morrison Formation	TENORM	147	0-12	2	0	0	0	0	2
3	Chíí dah wíih íeezh (Washes and Drainages)	Quaternary Alluvium	TENORM	17,391	0-6	0	0	0	0	17	17
4	Kee'da'whíí tééh (Full-Time Navajo Resident)	San Rafael Group	TENORM (Burial Cell 41)	115	12-72	0	0	0	0	0	0

Notes:

- a
- Surface soil overlying the burial cell is evaluated along with the EU in which the burial cell lies; therefore, the EU 1 total area includes the area of Burial Cell 41 in EU 4.
- bgs
- below ground surface
- EU
- Exposure unit
- m²
- Square meter
- TENORM
- Technologically enhanced naturally occurring radioactive material
- XRF
- X-ray fluorescence

Table 5. Summary Statistics for Exposure Units 1 through 3, All Depth Intervals

EU 1 - Kee'da'whíí tééh (Full-Time Navajo Resident) within the San Rafael Group												
COPC / COPEC	Units	Detection Frequency	Number of High Nondetect Results ^a	Minimum Concentration (qualifier)	Maximum Concentration (qualifier)	Location of Maximum Concentration	Arithmetic Mean ^b	UCL95 / Distribution ^{c, d}	Exposure Point Concentration			
									Value	Statistic ^e	Method ^f	
Surface Soil (0-12 inches bgs)												
Radium-226	pCi/g	4 / 4	0	3.8	20	M1-XS32-01-051218	9.7	--	20	Maximum	(1)	
Arsenic	mg/kg	5 / 13	0	1.2	3.6	M1-SB36-0612-01-091618	1.7	2.1 N	2.1	UCL	(4)	
Selenium	mg/kg	4 / 4	0	0.36 J	0.48 J	M1-SB36-0612-01-091618	0.40	--	0.48	Maximum	(1)	
Uranium	mg/kg	10 / 13	0	1.0	460	M1-SB36-0612-01-091618	41	263 NP	263	UCL	(17)	
Vanadium	mg/kg	12 / 13	0	20	170	M1-XS31-01-051218	66	108 LN	108	UCL	(10)	
EU 2 - Kee'da'whíí tééh (Full-Time Navajo Resident) within the Lower Morrison Formation												
COPC / COPEC	Units	Detection Frequency	Number of High Nondetect Results ^a	Minimum Concentration (qualifier)	Maximum Concentration (qualifier)	Location of Maximum Concentration	Arithmetic Mean ^b	UCL95 / Distribution ^{c, d}	Exposure Point Concentration			
									Value	Statistic ^e	Method ^f	
Surface Soil (0-12 inches bgs)												
Radium-226	pCi/g	0 / 0	0	--	--	--	--	--	--	--	--	
Arsenic	mg/kg	2 / 2	0	3.8	9.0	M1X38	6.4	--	9.0	Maximum	(1)	
Selenium	mg/kg	0 / 0	0	--	--	--	--	--	--	--	--	
Uranium	mg/kg	2 / 2	0	3.0	4.6	M1X38	3.8	--	4.6	Maximum	(1)	
Vanadium	mg/kg	0 / 2	0	--	--	--	--	--	--	--	--	
EU 3 - Chíí dah wiíh łeezh (Washes and Drainages) within the Quaternary Alluvium												
COPC / COPEC	Units	Detection Frequency	Number of High Nondetect Results ^a	Minimum Concentration (qualifier)	Maximum Concentration (qualifier)	Location of Maximum Concentration	Arithmetic Mean ^b	UCL95 / Distribution ^{c, d}	Exposure Point Concentration			
									Value	Statistic ^e	Method ^f	
Sediment (0-6 inches bgs)												
Radium-226	pCi/g	14 / 17	0	0.39 J-	0.98 J-	DM1-SD14-01-081918	0.50	0.58 G	0.58	UCL	(6)	
Arsenic	mg/kg	17 / 17	0	0.59	1.3	DM1-SD16-01-081918	0.85	0.93 N	0.93	UCL	(2)	
Selenium	mg/kg	0 / 17	0	--	--	Not Detected	--	--	--	--	--	
Uranium	mg/kg	17 / 17	0	0.30	0.70	DM1-SD2-01-081918	0.48	0.52 N	0.52	UCL	(2)	
Vanadium	mg/kg	17 / 17	0	3.0	5.5	DM1-SD14-01-081918	4.0	4.3 N	4.3	UCL	(2)	
EU 4 - Kee'da'whíí tééh (Full-Time Navajo Resident) Burial Cell 41 within the San Rafael Group												
COPC / COPEC	Units	Detection Frequency	Number of High Nondetect Results ^a	Minimum Concentration (qualifier)	Maximum Concentration (qualifier)	Location of Maximum Concentration	Arithmetic Mean ^b	UCL95 / Distribution ^{c, d}	Exposure Point Concentration			
									Value	Statistic ^e	Method ^f	
Subsurface Soil (12-72 inches bgs)												
No analytical data or XRF measurements were collected in EU 4.												

Table 5. Summary Statistics for Exposure Units 1 through 3, All Depth Intervals

Notes:

a	Number of nondetected results that exceeded the maximum detected concentration. These results were not included in the statistical calculations.					
b	The arithmetic mean for datasets with nondetected results is calculated using the Kaplan-Meier method.					
c	Following USEPA (2002, 2015) guidance, this value may be estimated by a 95, 97.5, or 99 percent UCL depending on the sample size, skewness, and degree of censorship.					
d	Tested using the Shapiro-Wilk W or Lilliefors test for normal and lognormal distributions and the Anderson-Darling and Kolmogorov-Smirnov tests for gamma distributions. A 5 percent level of significance was used in all tests. Distribution tests were conducted only for samples with at least four detected results. Distributions not confirmed as normal (N), lognormal (LN), or gamma (G) were treated as nonparametric (NP) in all statistical calculations.					
e	The EPC is the lesser of the UCL95 and the maximum detected result. The maximum detected result is the default when there are fewer than 10 samples or fewer than four detected results. All methods follow USEPA (2002, 2015).					
f	The statistical methods for selecting the exposure point concentration are as follows (not all are used):					
	(1)	Maximum detected concentration	(8)	95% Gamma Approximate KM-UCL	(14)	95% Chebyshev UCL
	(2)	95% Student's t UCL	(9)	95% H-UCL	(15)	95% KM Chebyshev UCL
	(3)	95% Modified-t UCL	(10)	95% H-UCL (KM log)	(16)	97.5% Chebyshev UCL
	(4)	95% KM (t) UCL	(11)	95% BCA Bootstrap UCL	(17)	97.5% KM Chebyshev UCL
	(5)	95% Adjusted Gamma UCL	(12)	95% Bootstrap-t UCL	(18)	99% Chebyshev UCL
	(6)	95% Gamma Adjusted KM-UCL	(13)	95% KM BCA UCL	(19)	99% KM Chebyshev UCL
	(7)	95% Approximate Gamma UCL				
--	Not applicable	H-UCL	UCL based upon Land's H-statistic		N	Normal distribution
BCA	Bias-corrected accelerated bootstrap method	J	Estimated value		NP	Nonparametric distribution
bgs	Below ground surface	J-	Estimated value, may be biased high		pCi/g	Picocurie per gram
COPC	Contaminant of potential concern	KM	Kaplan-Meier		UCL	Upper confidence limit of the mean
COPEC	Contaminant of potential ecological concern	KM (t)	UCL based upon Kaplan-Meier estimates		UCL95	One-sided 95 percent upper confidence limit
EPC	Exposure point concentration		using the Student's t-distribution critical value			on the mean
EU	Exposure unit	LN	Lognormal distribution		USEPA	U.S. Environmental Protection Agency
G	Gamma distribution	mg/kg	Milligram per kilogram		XRF	X-ray fluorescence

References:

U.S. Environmental Protection Agency (USEPA). 2002. "Calculating Exposure Point Concentrations at Hazardous Waste Sites." OSWER 9285.6-10. Office of Emergency and Remedial Response. December.

USEPA. 2015. "ProUCL Version 5.1 Technical Guide." Prepared by A. Singh and A.K. Singh. EPA/600/R-07/041. October.

Table 6. Risk-Based Soil Screening Levels for Human Health and Ecological Receptors

Human Receptors ^{a,b}							
Receptor	Age	Toxic Effect	Radium-226 (pCi/g)	Arsenic (mg/kg)	Selenium (mg/kg)	Uranium (mg/kg)	Vanadium (mg/kg)
Kee'da'whíí tééh (Full Time Residential)	Child+Adult	Cancer	0.11	0.62	--	--	--
	Child	Noncancer	--	0.31	5.8	0.92	27
	Adult	Noncancer	--	0.9	22	3.2	75
Chíí dah wiíh łeezh (Washes and Drainages)	Child+Adult	Cancer	0.65	5.5	--	--	--
	Child	Noncancer	--	2.7	64	8.8	180
	Adult	Noncancer	--	5.0	210	24	330

Ecological Receptors ^c					
Receptor	Radium-226 (pCi/g)	Arsenic (mg/kg)	Selenium (mg/kg)	Uranium (mg/kg)	Vanadium (mg/kg)
Plant	540	91	3	250	80
Soil Invertebrates ^d	15	68	41	NA	NA
Avian Herbivore ^d	340	340	1.9	15,000	13
Avian Ground Insectivore ^d	82	150	1.4	11,000	9.5
Avian Carnivore ^d	610	1,000	7.5	140,000	110
Mammalian Herbivore	3,400	180	3.4	2,600	1,500
Mammalian Ground Insectivore	5,100	31	1	1,200	610
Mammalian Carnivore	3,700	1,300	130	12,000	6,900

Notes:

- a The methodology and exposure inputs for calculating the human health RBSLs for cancer and noncancer are provided in the "Navajo Nation-Wide Risk Assessment Conceptual Site Model and Methodology" (Tetra Tech, Forthcoming).
- b The target cancer risk used in the RBSLs is three in ten thousand (3E-04) and the target noncancer hazard is 1.
- c Ecological RBSLs are LOECs based on Los Alamos National Laboratory ECORISK database low-effect level environmental screening levels (Newport News Nuclear BWXT-Los Alamos, LLC. 2020).
Screening levels for birds and mammals are low effect values for avian herbivores (American robin), avian ground insectivores (American robin), avian intermediate carnivores (American kestrel), mammalian herbivores (mountain cottontail), mammalian ground insectivores (montane shrew), and mammalian top carnivores (gray fox).
- d Soil invertebrates and avian receptors are exposed to surface soil (0-12 inches below ground surface) only.
- Not applicable
- LOEC Lowest observed effect concentration
- mg/kg Milligram per kilogram
- NA Not available
- pCi/g Picocurie per gram
- RBSL Risk-based screening level
- Tetra Tech Tetra Tech, Inc.

Table 6. Risk-Based Soil Screening Levels for Human Health and Ecological Receptors

References:

Newport News Nuclear BWXT-Los Alamos, LLC. 2020. "ECORISK Database (Release 4.2)." Document EM2020-0575, Los Alamos, New Mexico.

N3B 2020, 701067. November.

Tetra Tech, Inc. (Tetra Tech). Forthcoming. "Navajo Nation-Wide Risk Assessment Conceptual Site Model and Methodology. "

Table 7. Human Health Risk and Hazards Summary

EU 1 - Kee'da'whíí tééh (Full-Time Navajo Resident) within the San Rafael Group					
COPC ^a	Units	Exposure Point Concentration	Cancer Risk ^b	Noncancer Hazard ^b	
				Child	Adult
Surface Soil (0-12 inches bgs)					
Radionuclides ^c					
Radium-226	pCi/g	20	5.3E-02	--	--
Radionuclide Total			5E-02	--	--
Metals					
Arsenic	mg/kg	2.1	1.0E-03	6.8	2.3
Selenium	mg/kg	0.48	--	0.083	0.022
Uranium	mg/kg	263	--	286	82
Vanadium	mg/kg	108	--	4.0	1.4
Metal Total			1E-03	300	90
Grand Total			5E-02	300	90

EU 2 - Kee'da'whíí tééh (Full-Time Navajo Resident) within the Lower Morrison Formation					
COPC ^a	Units	Exposure Point Concentration	Cancer Risk ^b	Noncancer Hazard ^b	
				Child	Adult
Surface Soil (0-12 inches bgs)					
Radionuclides ^c					
Radium-226	pCi/g	--	--	--	--
Radionuclide Total			--	--	--
Metals					
Arsenic	mg/kg	9.0	4.3E-03	29	10
Selenium	mg/kg	--	--	--	--
Uranium	mg/kg	4.6	--	5.0	1.4
Vanadium	mg/kg	--	--	--	--
Metal Total			4E-03	30	10
Grand Total			4E-03	30	10

Table 7. Human Health Risk and Hazards Summary

EU 3 - Chíí dah wiíh łeezh (Washes and Drainages) within the Quaternary Alluvium					
COPC ^a	Units	Exposure Point Concentration	Cancer Risk ^b	Noncancer Hazard ^b	
				Child	Adult
Sediment (0-6 inches bgs)					
Radionuclides ^c					
Radium-226	pCi/g	0.58	2.7E-04	--	--
Radionuclide Total			3E-04	--	--
Metals					
Arsenic	mg/kg	0.93	5.1E-05	0.35	0.19
Selenium	mg/kg	--	--	--	--
Uranium	mg/kg	0.52	--	0.060	0.022
Vanadium	mg/kg	4.3	--	0.024	0.013
Metal Total			5E-05	0.4	0.2
Grand Total			3E-04	0.4	0.2

Notes:

a **Bolded** COPCs are selected as risk-based contaminants of concern because cancer risk is greater than 3E-04 or noncancer hazard is greater than 1.

b **Bolded** values are values greater than the target cancer risk of 3E-04 or noncancer target hazard of 1. Cancer risk is calculated by dividing the EPC by the cancer RBSL and multiplying by the target risk used for the cancer RBSL. Noncancer hazard is calculated by dividing the EPC by the noncancer RBSL for the age group evaluated. The methodology for calculating the risks and hazards, and the inputs for cancer and noncancer equations are provided in the "Navajo Nation-Wide Risk Assessment Conceptual Site Model and Methodology" (Tetra Tech, Forthcoming). Total risks and total hazards are reported to 1 significant digit; thus, values are commonly rounded. In practice, values can be slightly higher than the stated cutoff but still be considered equal to the cutoff because of rounding.

c For radionuclides, uranium-238 is assumed to be in secular equilibrium with its decay chain, meaning all decay chain nuclides are present in equal activity concentrations. In this case, the risk from radium-226 and its decay products (that is radium-226 in secular equilibrium) will account for most of the risk from the uranium-238 decay chain. Further information on secular equilibrium is provided in Section 2.4.3.

-- Not applicable

bgs Below ground surface

COPC Contaminant of potential concern

EPC Exposure point concentration

EU Exposure unit

mg/kg Milligram per kilogram

pCi/g Picocuries per gram

RBSL Risk-based screening level

Tetra Tech Tetra Tech, Inc.

XRF X-ray fluorescence

Reference:

Tetra Tech, Inc. (Tetra Tech). Forthcoming. "Navajo Nation-Wide Risk Assessment Conceptual Site Model and Methodology. "

Table 8. Human Health Risk-Based Contaminants of Concern Compared to Risk-Based Screening Levels and Background Threshold Values

EU 1 - Kee'da'whíí tééh (Full-Time Navajo Resident) within the San Rafael Group					
COC	Units	EPC ^a	Human Health RBSL ^b	BTV ^c	Is EPC > RBSL and BTV? ^d
Surface Soil (0-12 inches bgs)					
Radium-226	pCi/g	20	0.11	1.4	Yes
Arsenic	mg/kg	2.1	0.31	2.2	No
Uranium	mg/kg	263	0.92	0.90	Yes
Vanadium	mg/kg	108	27	9.7	Yes

EU 2 - Kee'da'whíí tééh (Full-Time Navajo Resident) within the Lower Morrison Formation					
COC ^e	Units	EPC ^a	Human Health RBSL ^b	BTV ^c	Is EPC > RBSL and BTV? ^d
Surface Soil (0-12 inches bgs)					
Arsenic	mg/kg	9.0	0.31	20	No
Uranium	mg/kg	4.6	0.92	7.3	No

EU 3 - Chíí dah wiíh łeezh (Washes and Drainages) within the Quaternary Alluvium					
COC	Units	EPC ^a	Human Health RBSL ^b	BTV ^c	Is EPC > RBSL and BTV? ^d
Sediment (0-6 inches bgs)					
<i>No contaminants of concern identified</i>					

Notes:

EU 4 is not included in this table because there are no analytical data or XRF measurements; therefore, risk and hazard cannot be calculated.

a EPCs are provided on Table 6.

b The human health RBSLs are provided on Table 6.

c The BTVs are provided on Table 2.

d If **Yes**, the COC should be considered for removal action. If **No**, the COC is not recommended for removal action based on the available data.

e EU 2 has two samples and only results for metals. Radium-226 is likely also a COC but will be evaluated using gamma readings.

bgs below ground surface

BTV Background threshold value

COC Contaminant of concern

EPC Exposure point concentration

EU Exposure unit

mg/kg Milligram per kilogram

pCi/g Picocurie per gram

RBSL Risk-based screening level

XRF X-ray fluorescence

Table 9. Ecological Risk Hazards Quotients

EU 1 - Kee'da'whíí tééh (Full-Time Navajo Resident) within the San Rafael Group											
COPEC ^a	Units	Exposure Point Concentration	Plant HQ	Soil Invertebrates HQ	Avian Herbivore HQ	Avian Ground Insectivore HQ	Avian Carnivore HQ	Mammalian Herbivore HQ	Mammalian Ground Insectivore HQ	Mammalian Carnivore HQ	Maximum HQ
Surface Soil (0-12 inches bgs)											
Radionuclides											
Radium-226	pCi/g	20	0.04	1	0.06	0.2	0.03	0.01	0.004	0.01	1
Metals											
Arsenic	mg/kg	2.1	0.02	0.03	0.01	0.01	0.002	0.01	0.07	0.002	0.07
Selenium	mg/kg	0.48	0.2	0.01	0.30	0.3	0.06	0.1	0.5	0.004	0.5
Uranium	mg/kg	263	1	--	0.02	0.02	0.002	0.1	0.2	0.02	1
Vanadium	mg/kg	108	1	--	8	10	1	0.07	0.2	0.02	10

EU 2 - Kee'da'whíí tééh (Full-Time Navajo Resident) within the Lower Morrison Formation											
COPEC ^a	Units	Exposure Point Concentration	Plant HQ	Soil Invertebrates HQ	Avian Herbivore HQ	Avian Ground Insectivore HQ	Avian Carnivore HQ	Mammalian Herbivore HQ	Mammalian Ground Insectivore HQ	Mammalian Carnivore HQ	Maximum HQ
Surface Soil (0-12 inches bgs)											
Radionuclides											
Radium-226	pCi/g	NS	NA	NA	NA	NA	NA	NA	NA	NA	NA
Metals											
Arsenic	mg/kg	9.0	0.10	0.1	0.03	0.06	0.01	0.05	0.3	0.007	0.3
Selenium	mg/kg	NS	NA	NA	NA	NA	NA	NA	NA	NA	NA
Uranium	mg/kg	4.6	0.02	--	0.0003	0.0004	0.00	0.00	0.004	0.0004	0.02
Vanadium	mg/kg	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA

EU 3 - Chíí dah wiíh leezh (Washes and Drainages) within the Quaternary Alluvium											
COPEC ^a	Units	Exposure Point Concentration	Plant HQ	Soil Invertebrates HQ	Avian Herbivore HQ	Avian Ground Insectivore HQ	Avian Carnivore HQ	Mammalian Herbivore HQ	Mammalian Ground Insectivore HQ	Mammalian Carnivore HQ	Maximum HQ
Sediment (0-6 inches bgs)											
Radionuclides											
Radium-226	pCi/g	0.58	0.001	0.04	0.002	0.007	0.001	0.0002	0.0001	0.0002	0.04
Metals											
Arsenic	mg/kg	0.93	0.01	0.01	0.003	0.006	0.0009	0.005	0.03	0.0007	0.03
Selenium	mg/kg	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA
Uranium	mg/kg	0.52	0.002	--	0.00003	0.00005	0.000004	0.0002	0.0004	0.00004	0.002
Vanadium	mg/kg	4.3	0.05	--	0.3	0.5	0.04	0.003	0.007	0.0006	0.5

Table 9. Ecological Risk Hazards Quotients

Notes:

HQ is calculated by dividing the EPC by the ecological RBSL. **Bolded** HQ values indicate HQs greater than 1. Ecological RBSLs are provided on Table 6. Ecological RBSLs are LOECs based on Los Alamos National Laboratory ECORISK database low effect level environmental screening levels (Newport News Nuclear BWXT-Los Alamos, LLC. 2020). Screening levels for birds and mammals are low-effect values for avian herbivore (American robin), avian insectivore (American robin), avian intermediate carnivore (American kestrel), mammalian herbivore (mountain cottontail), mammalian insectivore (montane shrew), and mammalian top carnivore (gray fox).

a	Bolded COPECs have a HQ greater than 1.
--	No screening level
bgs	Below ground surface
COPEC	Contaminant of potential ecological concern
EU	Exposure unit
HQ	Hazard quotient
mg/kg	Milligram per kilogram
NA	Not applicable
ND	Not detected
NS	Not sampled
pCi/g	Picocurie per gram
RBSL	Risk-based screening level

Reference:

Newport News Nuclear BWXT-Los Alamos, LLC. 2020. "ECORISK Database (Release 4.2)." Document EM2020-0575, Los Alamos, New Mexico. N3B 2020, 701067. November.

Table 10. Ecological Risk-Based Contaminants of Concern Compared to Risk-Based Screening Levels and Background Threshold Values

EU 1 - Kq̄q̄ eí doo nahaazáh dah (Difficult Access Open Space) within the San Rafael Group					
COPEC	Units	EPC ^a	Ecological RBSL ^b	BTV ^c	Is EPC > RBSL and BTV? ^d
Surface Soil (0-12 inches bgs)					
Vanadium	mg/kg	108	9.5	9.7	Yes

EU 2 - Kq̄q̄ eí nahaazáh (Easy Access Open Space) within the Salt Wash Member					
COPEC	Units	EPC ^a	Ecological RBSL ^b	BTV ^c	Is EPC > RBSL and BTV? ^d
Surface Soil (0-12 inches bgs)					
<i>No contaminants of ecological concern identified. ^d</i>					

EU 3 - Kq̄q̄ eí nahaazáh (Easy Access Open Space) within the Recapture Member					
COPEC	Units	EPC ^a	Ecological RBSL ^b	BTV ^c	Is EPC > RBSL and BTV? ^d
Surface Sediment (0-6 inches bgs)					
<i>No contaminants of ecological concern identified.</i>					

Notes:

EU 4 is not included in this table because there are no analytical data or XRF measurements; therefore, risk cannot be calculated.

a EPCs are provided on Table 6.

b The ecological RBSLs are provided on Table 7.

c The BTVs are provided on Table 2.

d If **Yes**, the COPEC is identified as a COEC and should be considered for removal action. If **No**, the COPEC is not recommended for removal action based on the available data.

e EU 2 has two samples and only results for metals.

bgs below ground surface

BTV Background threshold value

COEC Contaminant of ecological concern

COPEC Contaminant of potential ecological concern

EPC Exposure point concentration

EU Exposure unit

mg/kg Milligram per kilogram

RBSL Risk-based screening level

XRF X-ray fluorescence

Table 11. Risk-Based Screening Levels, Background Threshold Values, and Removal Action Goals

EU 1 - Kee'da'whíí tééh (Full-Time Navajo Resident) within the San Rafael Group						
COC / COEC ^a	Units	EPC ^b	Human Health RBSL ^c	Ecological RBSL ^c	BTV ^d	Removal Action Goal ^e
Surface Soil (0-12 inches bgs)						
Radium-226	pCi/g	20	0.11	--	1.4	1.4
Uranium	mg/kg	263	0.92	--	0.90	0.92
Vanadium	mg/kg	108	27	9.5	9.7	9.7

EU 2 - Kee'da'whíí tééh (Full-Time Navajo Resident) within the Lower Morrison Formation						
COC / COEC ^a	Units	EPC ^b	Human Health RBSL ^c	Ecological RBSL ^c	BTV ^d	Removal Action Goal ^e
Surface Soil (0-12 inches bgs)						
<i>No COCs or COECs were recommended for removal action ^f</i>						

EU 3 - Chíí dah wiíh íeezh (Washes and Drainages) within the Quaternary Alluvium						
COC / COEC ^a	Units	EPC ^b	Human Health RBSL ^c	Ecological RBSL ^c	BTV ^d	Removal Action Goal ^e
Sediment (0-6 inches bgs)						
<i>No COCs or COECs were identified.</i>						

Notes:

EU 4 is not included in this table because there are no analytical data or XRF measurements; therefore, risk cannot be calculated. Multiple lines of evidence are used in determining whether an EU will have a removal action; identification of COCs or COECs are two of these lines of evidence. Other lines of evidence include whether contamination is known to exist (such as in a burial cell) or the presence of elevated gamma radiation.

a The COCs are identified on Table 7 and the COECs are identified on Table 9. For radium-226, the human health RBSL assumes secular equilibrium of radium-226 and its decay products.

b The EPCs are provided on Table 5.

c The human health and ecological RBSLs are provided on Table 6. The human health RBSL is based on the receptor assumed at each EU. The ecological RBSL is based on the minimum lowest observed effects concentration for all feeding guilds evaluated for the depth interval.

d The BTVs are provided on Table 2.

e The removal action goal is the lesser of the human health and ecological RBSLs unless either RBSL is less than the BTV. If the BTV is higher than either RBSL, then the removal action goal is to address material that is distinguishable from background. For purposes of this Alternatives Analysis Memorandum, the BTV is used to represent background for delineating contaminated areas.

-- Not a COC or COEC

bgs below ground surface

BTV Background threshold value

COC Contaminant of concern

COEC Contaminant of ecological concern

EU Exposure unit

EPC Exposure point concentration

mg/kg Milligram per kilogram

pCi/g Picocurie per gram

RBSL Risk-based screening level

Table 12. General Response Actions, Technologies, and Process Options Screening Summary

General Response Actions	Response Action Technology	Process Options	Description	Screening Comment
No Action	None	Not applicable	No action	Not applicable
Institutional Controls	Access Restrictions	Land Use Controls	Implement administrative restrictions to control current and future land use, including traditional Navajo Lifeways.	Potentially effective in conjunction with other technologies; reduces opportunities for Navajo community exposure during typical land use activities. Protective in areas of a site with mineralized bedrock that cannot be addressed under CERCLA. Requires implementing authorities.
Engineering Controls	Access Restrictions	Fencing/Barrier	Install gate at road, fence around waste piles and mine shafts, and gates/barrier on adits to limit access.	Potentially effective in conjunction with other technologies; limits access to physical hazards and direct exposure to radionuclides and radon gas; however, would require annual inspection and repair for vandalism.
	Surface Controls	Consolidation, Grading, Revegetation, and Erosion Protection	Combine mine waste in a smaller common area. Return waste to mine openings, benches, and pits. Grade waste piles to reduce slopes for managing erosion and runoff. Add amendments and seed or revegetate to establish an erosion-resistant ground surface. Install sedimentation basins, run-on and run-off controls, and diversion ditches.	Effective in conjunction with other technologies; reduces physical hazards through backfilling of mine openings and pits; limits exposed waste surface area through consolidation; limits erosion of soil and migration to drainages; reduces storm water run-on and runoff; effective for material impinging on drainages; readily implementable. Does not fully address direct exposure, leaching, or potential wind erosion and migration off site.
		Soil Binder	Apply a chemical binder to soil to reduce wind and water erosion of soil.	Potentially effective in conjunction with other process options; limits mobility of metals and radionuclides to downwind receptors; does not address direct exposure, leaching, or stormwater erosion; not protective over long term; readily implementable.

Table 12. General Response Actions, Technologies, and Process Options Screening Summary

General Response Actions	Response Action Technology	Process Options	Description	Screening Comment
Engineering Controls	Containment	Earthen Cover	Apply soil cover over in situ or consolidated mine waste; establish vegetation to stabilize surface; waste materials are left in place. Reduces gamma and radon gas exposure.	Limits direct exposure and reduces gamma irradiation and radon gas flux; surface water infiltration would be reduced; should be combined with surface controls; implementable, but would require a somewhat flat area and regrading. Earthen covers on moderate to steep slopes not successful without benching. Retained for remote areas where access is limited and direct exposure and gamma irradiation reduction through soil shield is primary goal.
		Earthen Cover with Upper HDPE or Geosynthetic Clay Liner	Install clay layer, HDPE, or geosynthetic clay liner within cover over mine waste to reduce rainwater infiltration and radon flux; establish vegetation to stabilize surface; waste materials are left in place. Reduces gamma and radon exposure.	Limits direct exposure and reduces gamma irradiation; surface water infiltration and radon flux would be eliminated; should be combined with surface controls; implementable, but would require a somewhat flat area and regrading. Earthen cover on steep slopes are not successful without benching. Retained where leachate is a concern.
	On-Mesa/ Regional Disposal	Repository with Upper HDPE or Geosynthetic Clay Liner	Excavate mine waste and consolidate but outside the 100-year flood plain. Install clay layer, HDPE, or geosynthetic clay liner within cover over mine waste to reduce rainwater infiltration and radon flux; establish vegetation to stabilize surface. Reduces gamma and radon exposure.	Limits direct exposure, reduces gamma irradiation, and reduces the overall surface exposure area through consolidation; surface water infiltration and radon flux would be eliminated; should be combined with surface controls; readily implementable. Retained where in situ capping is not feasible and leachate is a concern.

Table 12. General Response Actions, Technologies, and Process Options Screening Summary

General Response Actions	Response Action Technology	Process Options	Description	Screening Comment
Engineering Controls	On-Mesa/ Regional Disposal	Repository with Encapsulating Geosynthetic Clay Liners	Excavate mine waste and consolidate outside the 100-year flood plain. Install upper and lower geosynthetic clay liner to prevent rainwater infiltration, reduce radon flux, and capture any generated leachate; apply soil cover and establish vegetation to stabilize surface. A leachate collection system would be needed which requires significant site preparation. Reduces gamma and radon exposure.	Limits direct exposure, reduces gamma irradiation, and reduces the overall surface exposure area through consolidation; surface water infiltration and radon flux would be eliminated; any potential leachate generated would be controlled by bottom liner and recovery system; should be combined with surface controls; readily implementable. An encapsulation system would only be required for high concentration and highly leachable waste. An isolation cell within a less controlled system should be considered where only small volumes of this type of waste are present.
	Off-Navajo Nation Disposal	Class A LLRW or RCRA C Hazardous Waste Disposal Facility	Excavate mine waste, sort, transport, and dispose of waste at an off-Navajo Nation Class A LLRW or RCRA C hazardous waste disposal facility; leachate generation characteristics may require stabilization.	Removes onsite direct exposure and gamma irradiation by isolating waste at an off-Navajo Nation LLRW or hazardous waste disposal facility where waste is covered or encapsulated; readily implementable. However, transport, any pretreatment, and disposal costs may be cost prohibitive because of the long haul distances required. Transportation costs should be weighed against long-term O&M costs associated with onsite disposal.
Excavation and Treatment	Physical/ Chemical Treatment	Milling/ Reprocessing	Excavate mine waste, sort, transport, and process waste at an operating mill for economic recovery of uranium; dispose of tailings at mill tailings disposal facility.	Removes onsite direct exposure and gamma irradiation by processing of waste at an off-Navajo Nation mill. Processed waste (tailings) are covered or encapsulated in a disposal cell; readily implementable. However, transport, milling, and disposal costs may be cost prohibitive because of the long haul distances required. Transportation costs should be weighed against long-term O&M costs associated with on-site disposal. A portion of the costs may be offset by economic value of uranium recovered.

Table 12. General Response Actions, Technologies, and Process Options Screening Summary

General Response Actions	Response Action Technology	Process Options	Description	Screening Comment
Excavation and Treatment	Physical/ Chemical Treatment	Acid Extraction	Excavate mine waste, sort, and screen waste to increase percentage of fines for acid digestion. Solubilize uranium and other metals via dissolution or acid leaching and recover by precipitation. Dispose of fines, process solutions, and oversize of materials.	Treatability testing required; effectiveness questionable; increases mobility by partial dissolution of contaminants; difficulty encountered because of gravel to rock sized waste rock and disseminated nature of uranium; increases toxicity of fines; requires disposal of treated fines and oversize material; cost prohibitive.
		Fixation/ Stabilization	Uses solidifying agents to facilitate a physical or chemical change in leachability and mobility of contaminants.	Treatability testing required; readily implementable; would still require disposal following stabilization; cost prohibitive as a pre-treatment step compared with a clay liner or geosynthetic clay upper liner within an earthen cover; feasible as a pretreatment option for a small volume of waste placed in an onsite or on-mesa isolation cell or for disposal off Navajo Nation where required to address contaminant leachability.
In-Place Treatment	Physical/ Chemical Treatment	Stabilization	Stabilize waste constituents in situ when combined with injected stabilizing agents.	Extensive treatability testing required; more difficulty encountered because of gravel to rock sized waste rock; does not reduce gamma irradiation; potentially implementable but requires a large amount of stabilizing agents and water for delivery (no water infrastructure); cost prohibitive.
		Solidification	Use solidifying agents in conjunction with deep soil mixing techniques to facilitate a physical or chemical change in the mobility of contaminants.	Extensive treatability testing required; more difficulty encountered because of gravel to rock sized waste rock; does not reduce gamma irradiation; potentially implementable but requires a large amount of solidifying agents and water for delivery (no water infrastructure); cost prohibitive.

Table 12. General Response Actions, Technologies, and Process Options Screening Summary

General Response Actions	Response Action Technology	Process Options	Description	Screening Comment
In-Place Treatment	Thermal Treatment	Vitrification	Uses extremely high temperature to melt and volatilize all components of the solid media; the molten material is cooled and, in the process, vitrified into a non-leachable form.	Extensive treatability testing required; difficulties may be encountered in establishing adequate control; does not reduce gamma irradiation; not implementable because of the remoteness of the site (no high voltage electrical infrastructure); cost prohibitive.
	Vegetative Treatment	Phytoextraction/ Phytostabilization	Uptake of contaminants by plant roots and accumulation of contaminants within plant shoots and leaves. Immobilization of contaminants at interfaces of roots and soil by absorption or adsorption; precipitation or complexation in root zone; binding to humic matter in root zone.	Extensive treatability testing required for phytostabilization of radionuclides; phytoextraction requires harvest and disposal of vegetative growth containing radionuclides, and fencing to exclude livestock and wildlife to prevent vegetative bioaccumulation. Long-term protectiveness has not been demonstrated and O&M costs may be prohibitive.

Notes:

Eliminated alternatives are shaded.

CERCLA Comprehensive Environmental Response, Compensation, and Liability Act
 EE/CA Engineering evaluation/cost analysis
 HDPE High-density polyethylene
 LLRW Low-level radioactive waste
 O&M Operation and maintenance
 RCRA Resource Conservation and Recovery Act

Table 13. Potential Federal and Tribal Chemical-Specific ARARs

Citation	Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL				
SOIL				
No potential chemical-specific ARARs are identified for metals or radionuclides or radioactivity in soil and waste rock at the Brodie 1 Mine. Preliminary removal action goals are risk-based goals and not ARAR-based standards.				
AIR				
Uranium Mill Tailings Radiation Control Act				
40 CFR § 192.02(b)	Control of residual radioactive materials and their listed constituents must be designed to assure that the release of radon-222 to the atmosphere: (1) not exceed an average (over the entire surface of the disposal site and over at least a one-year period) of 20 pCi/m ² -sec; or (2) not increase the annual average concentration of radon-222 in air at or above any location outside the disposal site by more than 0.5 pCi/L.	UMTRCA Title I Site	Relevant and appropriate	These standards are applicable to UMTRCA Title I Sites. The Brodie 1 Mine, onsite capping locations, and the new regional repository site are not Title I sites; therefore, these requirements are not applicable. These requirements have been determined to be relevant and appropriate to the onsite capping locations and new regional repository site, which consist of a disposal site for the contaminated soil and uranium waste rock from the Brodie 1 Mine. These standards apply to the design of the onsite caps and the new regional repository site.

Table 13. Potential Federal and Tribal Chemical-Specific ARARs

Citation	Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL				
Clean Air Act				
40 CFR §§ 61.222(a) and 61.223(a)	Radon-222 emissions to the ambient air from a uranium mill tailings pile that is no longer operational shall not exceed 20 pCi/m ² -sec. Testing shall be conducted in accordance with the procedures described in 40 CFR Part 61, Appendix B, Method 115, for 60 days after completion of the waste cover pile to limit radon emissions but before the long-term stabilization (defined as the addition of material on the pile for the purpose of ensuring compliance with the requirements of 40 CFR § 192.02[a]).	Non-operational uranium mill tailing disposal site	Relevant and appropriate	These requirements are applicable to non-operational uranium mill tailings piles. The Brodie 1 Mine does not contain uranium mill tailings and none of the waste to be disposed of on site or in the new regional repository site are uranium mill tailings. These requirements have been determined to be relevant and appropriate for onsite capping and the new regional repository sites, which consist of a disposal site for the uranium waste rock from the Brodie 1 Mine. Testing must be completed for 60 days after completion of the waste pile cover to limit radon emission but before long-term stabilization.
TRIBAL				
No potential chemical-specific tribal ARARs are identified for metals or radionuclides or radioactivity in soil or in air emissions at the Brodie 1 Mine. Preliminary removal action goals are risk-based goals and not ARAR-based standards.				

Notes:

§	Section
§§	Sections
ARAR	Applicable or relevant and appropriate requirement
CFR	<i>Code of Federal Regulations</i>
pCi/L	Picocurie per liter
pCi/m ² -sec	Picocurie per square meter per second
UMTRCA	Uranium Mill Tailing Radiation Control Act

Table 14. Potential Federal and Tribal Location-Specific ARARs

Citation	Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL				
BIOLOGICAL RESOURCES				
Endangered Species Act				
16 U.S.C. §§ 1536(a)(2) and 1538 50 CFR § 17.11, 17.21, and 17.31(a)	Federal agencies may not carry out actions that jeopardize the continued existence of any listed species. It is unlawful to take a threatened or endangered species or cause the destruction or modification of critical habitat.	Presence of a threatened or endangered species	Applicable	No threatened or endangered species were identified within the area of the site.
CULTURAL RESOURCES				
National Historic Preservation Act				
54 U.S.C. §§ 306101, 306102, 306107, and 306108 36 CFR Part 800	Federal agencies are required to protect historic properties and to take into account the effect of their actions on historic properties. Federal agencies must consult with THPO to determine whether proposed federal actions will have an adverse effect on historic properties and to identify alternatives or modifications to the proposed action to avoid, minimize, or mitigate adverse effects.	Property included on or eligible for the National Register of Historic Places	Applicable	Cultural resource surveys completed during field investigations in 2018 identified one or more locations with a culturally significant resource at the Brodie 1 Mine. Other areas may be disturbed during implementation of removal actions. These areas would require evaluation for the presence of culturally significant resources. If found during the survey or during earth-moving activity, USEPA would work with THPO to determine if the resources would be adversely affected.

Table 14. Potential Federal and Tribal Location-Specific ARARs

Citation	Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL				
Preservation of Historical and Archaeological Data Act				
54 U.S.C. §§ 312502 and 312503	When federal agency action may cause irreparable loss or destruction of significant scientific, prehistorical, historical, or archaeological data, the federal agency may recover, protect, and preserve the data requested.	Federal agency action that would cause irreparable loss to significant historic or archaeological data.	Applicable	Cultural resource surveys completed during field investigations in 2018 identified one or more locations with a culturally significant resource at the Brodie 1 Mine. Other areas may be disturbed during implementation of removal actions. These areas would require evaluation for the presence of significant historic or archaeological data. If found during the survey or during earth-moving activity, USEPA would work with THPO to determine necessary preservation actions.
Native American Graves Protection and Repatriation Act				
25 U.S.C. §§ 3001-3013 43 CFR §§ 10.4, 10.5, 10.6, and 10.7	When human remains, funerary objects, sacred objects, or objects of cultural patrimony on federal or tribal lands are discovered on tribal land, the responsible tribe must be notified, activity in the area must stop, and consultation with the tribe must be initiated to determine proper ownership and custody.	Excavation on federal or tribal land.	Applicable	Cultural resource surveys completed during field investigations in 2018 identified one or more locations with a culturally significant resource at Brodie 1 Mine. Other areas may be disturbed during implementation of removal actions. These areas would require evaluation for the presence of remains of objects or archaeological data. If found during the survey or during earth-moving activity, USEPA would work with THPO to determine proper ownership and custody.

Table 14. Potential Federal and Tribal Location-Specific ARARs

Citation	Requirement	Prerequisite	Preliminary ARAR Determination	Comments
TRIBAL				
CULTURAL RESOURCES				
Navajo Nation Endangered Species Act				
Navajo Nation Code, Title 4, Chapter 3, Subchapter 21 § 507(A) and (C)	It is unlawful for anyone to take, possess, transport, export, process, sell, offer for sale, or ship any species appearing on any of the following lists: (1) the list of endangered species developed by the Navajo Nation Council; or (2) U.S. threatened or endangered species list.	A species on the Navajo Nation Council list or on the U.S. threatened or endangered species list	Applicable	No threatened or endangered species were identified at the Brodie 1 Mine. Although MSO surveys were not performed within the Tse Tah Wash watershed, the Brodie 1 Mine and the potential regional repository near the Block K Mine do not provide suitable MSO habitat.
Navajo Nation Cultural Resources Protection Act				
Navajo Nation Code, Title 19, Chapter 11 § 1021	The sponsor of any undertaking on Navajo land must obtain the approval from the Preservation Officer before implementation of the undertaking to ensure protection of cultural resources.	Undertaking on Navajo lands	Applicable	Cultural resource surveys completed during field investigations in 2018 identified one or more locations with a culturally significant resource at the Brodie 1 Mine. Other areas may be disturbed during implementation of removal actions. These areas would require evaluation for the presence of cultural resources. If found during the survey or during earth-moving activity, USEPA would work with THPO to determine appropriate protection measures.

Notes:

§

Section

THPO

Tribal Historic Preservation Office

§§

Sections

U.S.C.

United States Code

ARAR

Applicable or relevant and appropriate requirement

USEPA

U.S. Environmental Protection Agency

CFR

Code of Federal Regulations

MSO

Mexican spotted owl

Table 15. Potential Federal and Tribal Action-Specific ARARs

Action	Alternatives	Citation	Summary of Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL						
Clean Water Act						
Excavation at the Brodie 1 Mine, repair of the burial cell, and construction of the repository	2, 3, 4, 5	33 U.S.C. § 1342(p)(3)(A) 40 CFR § 122.44(k)(2)	Construction activity that affects 1 acre or more must use best management practices to control stormwater discharge.	Construction activity that effects 1 acre or more.	Applicable	The excavation at the Brodie 1 Mine, repair of the burial cell, and construction of the repository will affect more than 1 acre. Best management practices would be used to control stormwater discharge.
Uranium Mill Tailings Radiation Control Act						
Construction of the cap on the burial cell or repository	2, 3	40 CFR § 192.02(a)	The design for the control of residual radioactive materials must be effective for up to 1,000 years to the extent reasonably achievable and, in any case, for at least 200 years.	UMTRCA Title I uranium mill site	Relevant and appropriate	The UMTRCA design standard is not applicable to the capped burial cell and repository. However, the requirement is identified as relevant and appropriate because the onsite capped areas will control residual radioactive materials similar to an UMTRCA disposal site and will be considered to the extent practicable.

Table 15. Potential Federal and Tribal Action-Specific ARARs

Action	Alternatives	Citation	Summary of Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL						
Construction of the cap on the burial cell or repository	2, 3	40 CFR § 192.02(d)	The uranium mill tailings disposal site must be designed and stabilized in a manner that minimizes the need for future maintenance.	UMTRCA Title I uranium mill site	Relevant and appropriate	The UMTRCA standard is not applicable to the capped burial cell and repository. However, the requirement is identified as relevant and appropriate because the burial cell and repository will control residual radioactive materials similar to an UMTRCA disposal site.
Atomic Energy Act						
Construction of the cap on the burial cell or repository	2, 3	10 CFR Part 40, Appendix A, Criterion 1	Uranium mill tailings disposal site selection criteria, including (1) remoteness; (2) natural conditions that contribute to the continued immobilization and isolation of contaminants from groundwater sources; (3) potential for minimizing erosion, disturbance, and dispersion by natural forces; and (4) disposed in a manner that no active maintenance is required to preserve site conditions.	NRC-licensed uranium mill tailings disposal site	Relevant and appropriate	These requirements are not applicable to the capped burial cell and repository. However, the requirements are identified as relevant and appropriate because the burial cell and repository will control residual radioactive materials.

Table 15. Potential Federal and Tribal Action-Specific ARARs

Action	Alternatives	Citation	Summary of Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL						
Construction of the cap on the burial cell or repository	2, 3	10 CFR Part 40, Appendix A, Criterion 1	Uranium mill tailings disposal site design criteria, including (1) topographic features that provide good wind protection; (2) relatively flat cover slopes to minimize erosion; (3) full self-sustaining vegetative or rock cover to reduce wind and water erosion; (4) located away from a fault that could cause a maximum credible earthquake larger than what the impoundment could reasonably withstand; and (5) incorporate features that promote deposition where feasible.	NRC-licensed uranium mill tailings disposal site	Relevant and appropriate	These requirements are not applicable to the capped burial cell and repository. However, the requirements are identified as relevant and appropriate because the burial cell and repository will control residual radioactive materials.

Table 15. Potential Federal and Tribal Action-Specific ARARs

Action	Alternatives	Citation	Summary of Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL						
Construction of the cap on the burial cell or repository	2, 3	10 CFR Part 40, Appendix A, Criterion 6(1)	Tailings must be covered by an earthen cover or approved appropriate alternative that (1) provides reasonable assurance of control of radiological hazards; (2) is effective for 1,000 years to the extent reasonably achievable and for at least 200 years; and (3) limits the release of radon-222 to the atmosphere so as not to exceed an average release rate of 20 pCi/m ² -sec to the extent practicable throughout the effective design life. Excess moisture in soil may not be considered; direct gamma exposure should be reduced to background; the effects of any thin synthetic layer may not be taken into account in calculating radon exhalation level; and non-soil covers must be demonstrated to not crack or degrade by differential settlement, weathering, or other mechanism.	NRC-licensed uranium mill tailings disposal site	Relevant and appropriate	These requirements are not applicable to the capped burial cell and repository. However, the requirements are identified as relevant and appropriate because the burial cell and repository will control residual radioactive materials. Three different types of covers, including an earthen cover, are evaluated for the onsite caps. All covers would achieve the radon-222 emission standard (not to exceed 20 pCi/m ² -sec) in this criterion and in the potential chemical-specific ARARs.

Table 15. Potential Federal and Tribal Action-Specific ARARs

Action	Alternatives	Citation	Summary of Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL						
Construction of the cap on the burial cell or repository	2, 3	10 CFR Part 40, Appendix A, Criterion 6(3)	When the final radon barrier is placed in phases, verification of the radon-222 release rate must be completed for each portion of the final radon barrier as it is emplaced.	NRC-licensed uranium mill tailings disposal site	Relevant and appropriate	These requirements are not applicable to the capped burial cell and repository. However, the requirements are identified as relevant and appropriate because the burial cell and repository will control residual radioactive materials. Construction may occur over more than one season. If this occurs, the radon barrier will be tested when placed.
Construction of the cap on the burial cell or repository	2, 3	10 CFR Part 40, Appendix A, Criterion 6(5)	Prohibiting near-surface materials from including waste or rock that contains elevated levels of radium, requiring that soils used for near-surface cover be essentially the same as far as radioactivity is concerned.	NRC-licensed uranium mill tailings disposal site	Relevant and appropriate	These requirements are not applicable to the capped burial cell and repository. However, the requirement is identified as relevant and appropriate because the burial cell and repository will control residual radioactive materials. Soil cover material will be obtained from nearby borrow sources.

Table 15. Potential Federal and Tribal Action-Specific ARARs

Action	Alternatives	Citation	Summary of Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL						
Construction of the cap on the burial cell or repository	2, 3	10 CFR Part 40, Appendix A, Criterion 6(7)	Disposal sites must be closed in a manner that minimizes the need for further maintenance and, to the extent necessary, to control, minimize, or eliminate post-closure escape of non-radiological hazardous constituents, leachate, contaminated rainwater, or waste decomposition products to the ground or surface waters or atmosphere.	NRC-licensed uranium mill tailings disposal site	Relevant and appropriate	These requirements are not applicable to the capped burial cell and repository. However, the requirements are identified as relevant and appropriate because the burial cell and repository will control residual radioactive materials. The containment of the radionuclides will also adequately contain the metals to prevent escape to other environmental media.
TRIBAL						
Close, stabilize, or repair adits	2, 3, 4, 5	Navajo Nation Code, Title 18, Chapter 15 § 1639(A)	Open and abandoned tunnels, shafts, and entryways from previous mining operations may be sealed to prevent public health or safety hazards	Open and abandoned tunnels, shafts, or entryway declared by the Director of Abandoned Mine Lands Reclamation Department to be a hazard to public health or safety	Relevant and appropriate	In 1988, the Navajo Nation received approval for its NAML RP. Therefore, NAML RP requirements were reviewed as potential ARARs instead of the requirements in the federal SMCRA. This provision is not applicable to closing, stabilizing, or repairing adits as part of the removal action. However, this is identified as relevant and appropriate to closing the adits to prevent access to the mines.

Table 15. Potential Federal and Tribal Action-Specific ARARs

Notes:

§	Section
§§	Sections
ARAR	Applicable or relevant and appropriate requirement
CFR	<i>Code of Federal Regulations</i>
NAMLRP	Navajo Abandoned Mine Land Reclamation Program
NRC	Nuclear Regulatory Commission
pCi/m ² -sec	picocuries per square meter per second
SMCRA	Surface Mining Control and Reclamation Act
UMTRCA	Uranium Mill Tailings Radiation Control
U.S.C.	<i>United States Code</i>

Table 16. Site Restoration Matrix for Brodie 1 Mine

Restoration Areas	Surficial Restoration Type	Access Controls		Construction BMPs				Road Erosion Controls		Drainage Erosion Controls		Steep Slope Erosion Controls			Common Erosion Controls			
		Fencing/ Road Barriers	Portal Closure	Contouring and Inward Grading For Drainage	Benching/ Laying Back Steep Slopes and Highwalls	Pulling Overbank Material onto Road Cut	Grading Drainage for Energy Grade Line	Water Control Bars	Rock Crossings/ Culverts	Gabion Weir	Rocks/ Boulders/ Structures for Energy Dissipation	Gabion Wall	Articulated Concrete Matting	Shotcrete	Diverting Water Using Berms/ Ditches	Sediment Detention Basin/ Infiltration Gallery	Revegetation (Planting/ Seeding)	Blankets, Wattles, Coir Logs
Roads	Construction Access Road on Flat Land																	
	Construction Access Roads Crossing Drainage																	
Mine Features	Benches, Rimstrips, and Portals with Highwalls																	
	Intact Burial Cell Covers																	
Excavated Areas	Excavated Areas on Shallow Slopes																	

Notes:

	Green shading means a restoration approach is applicable for a site area
	Yellow shading means a restoration approach is potentially applicable for a site area
	No shading means a restoration approach is not applicable for a site area

BMP Best management practice

Table 17. Analysis of Alternatives for Brodie 1 Mine

Alternative		Threshold Criteria		Effectiveness		Implementability		Cost
		Protective of Human Health and the Environment	Compliance with ARARs	Short Term (During Action)	Long Term (After Action)	Technical Feasibility/ Availability of Services and Materials	Administrative Feasibility	\$ (Million Dollars)
1	No Action	Not Protective	Not in Compliance	Very Good	Very Poor	Very Good	Very Good	Very Good \$0
2	Consolidation and Capping	Protective	In Compliance	Good	Average	Very Good	Very Good	Poor \$3.1
3	Excavation, Transport, and Disposal in On-Navajo Nation Regional Repository	Protective	In Compliance	Average	Good	Very Good	Average	Average \$2.7
4	Excavation, Off-Navajo Nation Transport, and Disposal at White Mesa Mill	Protective	In Compliance	Poor	Very Good	Good	Good	Good \$2.3
5	Excavation, Off-Navajo Nation Transport, and Disposal at Hazardous Waste or Low-Level Radioactive Waste Facility	Protective	In Compliance	Very Poor	Very Good	Very Good	Good	Average \$2.8

Note:

ARAR Applicable or relevant and appropriate requirement

APPENDIX A

SITE IMAGES

The Google Earth Aerial Image displays the Brodie 1 Mine and associated features.

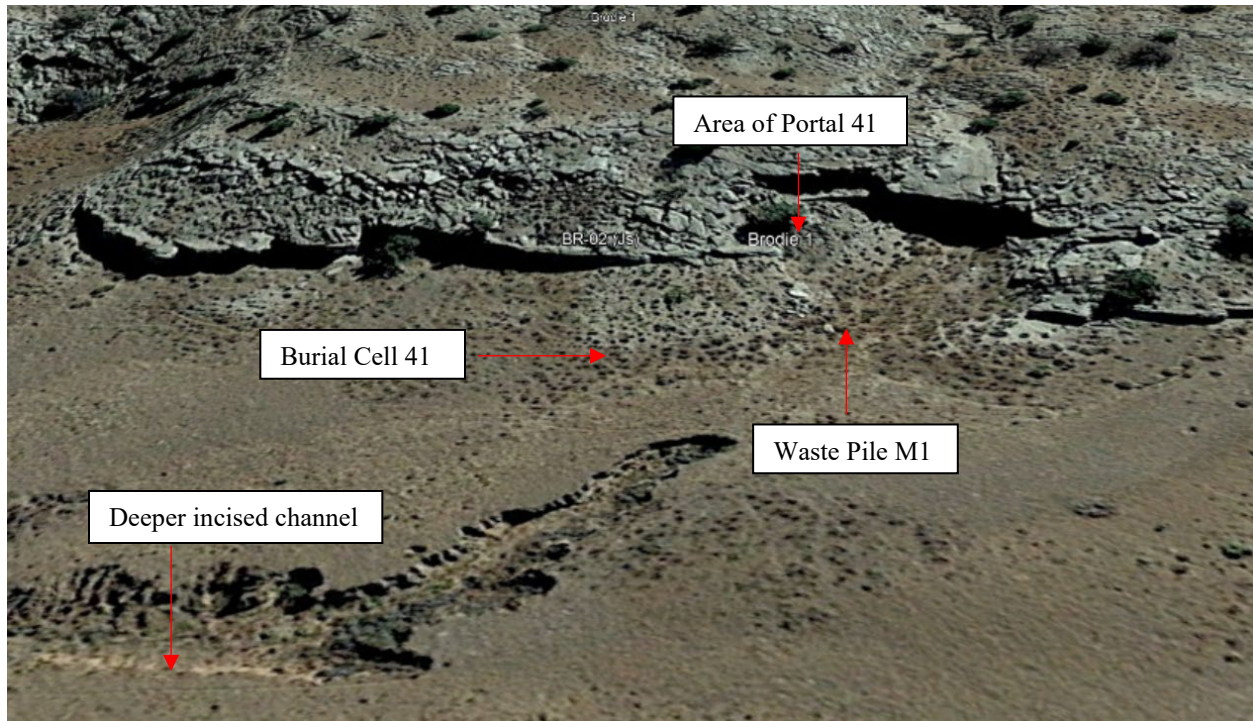


IMAGE 1

Date: Google Earth Aerial Image obtained 9/14/21

Location: Brodie 1 Mine

Description: Deeper incised channel enters the Tse Tah West drainage downstream. A small drainage runs through the site and over the sandstone cliff above the portal into Waste Pile M1. This drainage connects to the deeper incised channel shown. Image viewed from southeast direction (Google Earth Pro).

The following photographs were taken during the removal site evaluation (RSE) field investigation of the Brodie 1 Mine.



PHOTOGRAPH 1

Date: 5/12/18

Location: Brodie 1 Mine

Description: Reclaimed Portal 41



PHOTOGRAPH 2

Date: 5/12/18

Location: Brodie 1 Mine

Description: Reclaimed Portal 41, closed with a cement block bulkhead



PHOTOGRAPH 3

Date: 8/19/18

Location: Brodie 1 Mine

Description: Unreclaimed Waste Pile M1 and reclaimed Portal 41 overlain with waste material; Waste Pile M1 was mapped as a new unreclaimed waste pile



PHOTOGRAPH 4

Date: 8/19/18

Location: Brodie 1 Mine

Description: Burial Cell 41 and remaining waste and incised channel; sparse vegetation within the burial cell compared to other portions of the site indicating disturbance from past mining and reclamation activities



PHOTOGRAPH 5

Date: 5/23/18

Location: Brodie 1 Mine

Description: Rock and soil berm upslope of the mine; berm intercepts sheet flow and diverts water to the drainage west of the site

APPENDIX B

SITE DELINEATION

Tronox Navajo Area Uranium Mines Northern Abandoned Uranium Mine Region

Appendix B: Site Delineation

Brodie 1 Mine Alternatives Analysis Memorandum

Response, Assessment, and Evaluation Services

Contract No. EP-S9-17-03

Task Order 0016

September 30, 2021

Submitted to

U.S. Environmental Protection Agency

Submitted by

Tetra Tech, Inc.

1999 Harrison Street, Suite 500

Oakland, CA 94612



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ACRONYMS AND ABBREVIATIONS

AUM	Abandoned uranium mine
BTV	Background threshold value
MARSSIM	<i>Multi-Agency Radiation Survey and Site Investigation Manual</i>
NORM	Naturally occurring radioactive material
Ra-226	Radium-226
RSE	Removal site evaluation
Site	Brodie 1 Mine
TENORM	Technologically enhanced naturally occurring radioactive material
Tetra Tech	Tetra Tech, Inc.
USEPA	U.S. Environmental Protection Agency

1.0 INTRODUCTION

The purpose of this appendix is to describe the methods and observations that are used to identify and delineate naturally occurring radioactive material (NORM) and technologically enhanced naturally occurring radioactive material (TENORM) at the Brodie 1 Mine (Site).

NORM and TENORM boundaries are defined based on site reconnaissance observations and evaluation of removal site evaluation (RSE) data (Tetra Tech, Inc. [Tetra Tech] 2019) in accordance with the *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) (U.S. Environmental Protection Agency [USEPA] 2000), “Technical Report on Technologically Enhanced Naturally Occurring Radioactive Materials from Uranium Mining” (USEPA 2008), “NORM-TENORM Determinations and Delineation” (USEPA 2021a), and “Mining Forensics and Physical Disturbance Guidance” (USEPA 2021b) at abandoned uranium mines (AUM). NORM and TENORM boundaries do not necessarily correspond to impacted and non-impacted areas at a site. Definitions for impacted and non-impacted areas and for NORM and TENORM in the above guidance documents are provided below.

MARSSIM (USEPA 2000) does not provide guidance on NORM and TENORM delineation but does provide guidance on categorizing site areas as follows: “Categorization is the act or result of separating an area or survey unit into one of two categories: impacted or non-impacted. Areas that have no reasonable potential for residual radioactive material are categorized as non-impacted areas. These areas have no radiological impact from site operations and are typically identified early in the cleanup process. Areas with some reasonable potential for residual radioactive material are categorized as impacted areas.”

USEPA (2008) defines TENORM as, “Naturally occurring radioactive materials that have been concentrated or exposed to the accessible environment as a result of human activities such as manufacturing, mineral extraction, or water processing.” Technologically enhanced means that “the radiological, physical, and chemical properties of the radioactive material have been concentrated or further altered by having been processed, or beneficiated, or disturbed in a way that increases the potential for human and/or environmental exposures.”

USEPA (2008) defines NORM as, “Materials which may contain any of the primordial radionuclides or radioactive elements as they occur in nature, such as radium, uranium, thorium, potassium, and their radioactive decay products, such as radium and radon, that are undisturbed as a result of human activities.”

According to USEPA (2021a), a feature is defined as TENORM at an AUM if it (1) has been processed, beneficiated, or otherwise disturbed (hereinafter referred to as disturbed) by mining activities; and (2) increases or could increase exposure to human health and the environment.

Based on the above definitions, an area that was physically disturbed can be classified as TENORM and non-impacted. Not all TENORM areas contain levels of radium-226 (Ra-226) or other contaminants of potential concern that require cleanup.



Disturbance at AUMs is divided into mechanical processes and transport processes (USEPA 2021b) as follows:

- Mechanical or geochemical disturbance of rock or soil and mechanical transport of those materials by direct mining activities. For example, dewatering ponds; excavating pits, adits, or shafts; pushing waste piles off cliffs; and ore spilling from haul trucks.
- Natural geologic or geomorphic disturbance of rock or soil and mechanical transport of those materials by gravity, wind, and water. For example, erosion triggered by mechanical disturbance that exposes contaminants that were not present at the surface before mining.

2.0 LINES OF EVIDENCE AND SITE DELINEATION METHODS

During the NORM-TENORM delineation, the following lines of evidence were examined using the processes described below:

- ***Mapped Mine Features:*** Mine features such as waste piles, highwalls, rimstrips, and portals are defined as TENORM. As a starting point to mapping TENORM, the following buffer areas were applied to mine features:
 - Berms, highwalls, and portals received a buffer of 5 meters; 5 meters was selected to conservatively map TENORM and to account for minor inaccuracies in global positioning system locations.
 - Field-mapped features such as pipes and mine debris received a buffer of 2 meters.
- ***Site History and Known Reclamation Activities:*** Reclamation features such as reclaimed rimstrips, reclaimed waste rock piles, covered benches, burial cells, and reclaimed portals are defined as TENORM. Depending on the material used, some reclamation features, such as berms, may be classified as disturbed NORM.
- ***Transport Features:***
 - Surface water pathways below mine features received a buffer of 5 meters and the buffer was extended based on gamma data.
 - A downgradient assessment of transport from mine features toward surface water pathways determined additional areas within the survey area boundary where transport is likely to occur.
 - A light detection and ranging aerial imagery and hillshades assessment identified any mass wasting areas from roads or other features and evaluated losses in vegetation potentially related to disturbances.
- ***Gamma Radiation Data and Estimated Ra-226 Data:*** Gamma radiation and estimated Ra-226 data were used to evaluate areas impacted by mining and where exposure to humans or the environment has been increased.
- ***Geologic Mapping:***
 - Undisturbed areas within the Salt Wash Member of the lower Morrison Formation ore host rock unit are classified as NORM.
 - Areas within the host rock unit and disturbed in a way that increases contaminant mobility and risk to receptors, are classified as TENORM.

3.0 NORM AND TENORM SITE DELINEATION RESULTS

This section presents the results from the NORM-TENORM delineation. [Figure B-1](#) through [Figure B-9](#) show the lines of evidence, including supporting Site data and photographs, used to conduct the NORM-TENORM delineation. The NORM-TENORM delineation should be field-verified for accuracy.

At the Brodie 1 Mine, the raw and interpolated estimated Ra-226 concentrations (as converted from Brodie 1 Mine gamma survey data), geology, and the mapped Site features were used as the primary lines of evidence for delineating NORM and TENORM. [Figure B-1](#) presents both the Site Features (including mine features, reclamation features, and transport features), and the estimated Ra-226 surface soil concentrations. All mine and reclamation features, including the reclaimed portal, reclaimed waste pile, unreclaimed waste pile, burial cell, and associated berm are mapped as TENORM. Additionally, transport areas and a small rockfall pile surveyed downgradient of the portal, waste pile, and burial cell are mapped as TENORM.

[Figure B-2](#) presents the interpolated estimated Ra-226 data, and [Figure B-3](#) presents the interpolated estimated Ra-226 concentrations within the TENORM boundary. Data were only interpolated within the Site boundary; therefore, the estimated Ra-226 data are not shown for features outside the Site boundary on [Figure B-2](#) or [Figure B-3](#). Surface water that passes through the Brodie 1 Mine flows into the Tse Tah West Wash; [Figure B-4](#) presents the estimated Ra-226 concentrations for the Tse Tah West Wash and nearby tributaries.

One feature included in the Site gamma survey and shown in [Figure B-1](#) lies outside the Site boundary in an area near the drainage that runs adjacent to the western edge of the Site. The estimated Ra-226 concentrations in this area are at or slightly above the background threshold value (BTV). The elevated concentrations and potential for transport to the nearby drainage provided lines of evidence for including this within the TENORM boundary.

Brodie 1 Mine encompasses two geologic units. The northwestern portion of the Site lies within the San Rafael Group and the southeastern portion of the Site lies in the lower Morrison Formation. The lower Morrison Formation is considered the host rock unit for uranium. The estimated and interpolated estimated Ra-226 concentrations ([Figure B-1](#) and [Figure B-2](#)) in the lower Morrison Formation are below the BTV. As a result, this entire region (including the areas upslope of the reclaimed portal, reclaimed waste pile, unreclaimed waste pile, and burial cell), is considered NORM. One exception is the berm which is a reclamation feature and, therefore, considered TENORM.

The Tse Tah West Wash downstream of the Brodie 1 Mine lies within the Quaternary Alluvium geologic unit ([Figure B-4](#)). Estimated Ra-226 concentrations in the Tse Tah West Wash downstream of the Brodie 1 Mine are lower than the Quaternary Alluvium BTV, indicating that transport from Brodie 1 Mine has not impacted the drainage; therefore, the Tse Tah West Wash is not considered TENORM. In a scanned tributary northeast of Brodie 1 Mine that lies within the San Rafael Group, estimated Ra-226 concentrations are above the San Rafael Group BTV, likely because NORM from the lower Morrison Formation has been transported into the tributary via erosion and surface water transport. The Brodie 1 Mine surface water pathways do not contribute to this tributary.

The area just north of Burial Cell 41 showed low-density vegetation from the observed aerial photograph seen in [Figure B-5](#). The impact is likely from previous mining activities. As a result, this area is included in the TENORM boundary in [Figure B-1](#). In [Figure B-1](#) there are areas west and north of the mining and reclamation features that show concentrations of Ra-226 that are at or above the BTV. However, the estimated interpolated Ra-226 data in these regions in [Figure B-2](#) is below the BTV. The estimated interpolated Ra-226 data was weighted more heavily than the raw estimated Ra-226 results during the evaluation of all lines of evidence. As a result, these two areas were not mapped as TENORM. Other areas of the Site within the San Rafael Group with no evidence of mining disturbance and where the interpolated estimated Ra-226 was at or below the BTV were not included in the TENORM boundary.

[Figure B-6](#) and [Figure B-7](#) present photographs that show the NORM and TENORM areas at the Site. Both [Figure B-6](#) and [Figure B-7](#) show the reclaimed portal and waste pile below the portal that are within the TENORM boundary. The NORM area upslope of the mine within the lower Morrison Formation is also shown in [Figure B-6](#) and [Figure B-7](#). The reclaimed Portal 41 is shown in [Figure B-8](#). In addition, [Figure B-9](#) shows the TENORM areas of the burial cell and reclaimed portal, as well as the head-cutting drainage present at the Site. The head-cutting drainage is not mining related.

In summary, the following features and areas were mapped as TENORM at the Brodie 1 Mine:

- Unreclaimed and reclaimed waste piles
- Burial cell and surrounding disturbed areas
- Reclaimed portal
- Rock berm
- Contaminated surface soils resulting from transport
- Drainage path leaving the Site

Not all of the TENORM features contain measured and interpolated concentrations of Ra-226 above the BTV, which is the removal action goal at the Brodie 1 Mine. Only TENORM areas with Ra-226 concentrations above the BTV or that are considered sources of contamination are recommended for cleanup.



4.0 REFERENCES

Tetra Tech, Inc. (Tetra Tech). 2019. “Northern Agency Tronox Mines Removal Site Evaluation Report.” Response, Assessment, and Evaluation Services. Contract No. EP-S9-17-02. Task Order 0001. October 10.

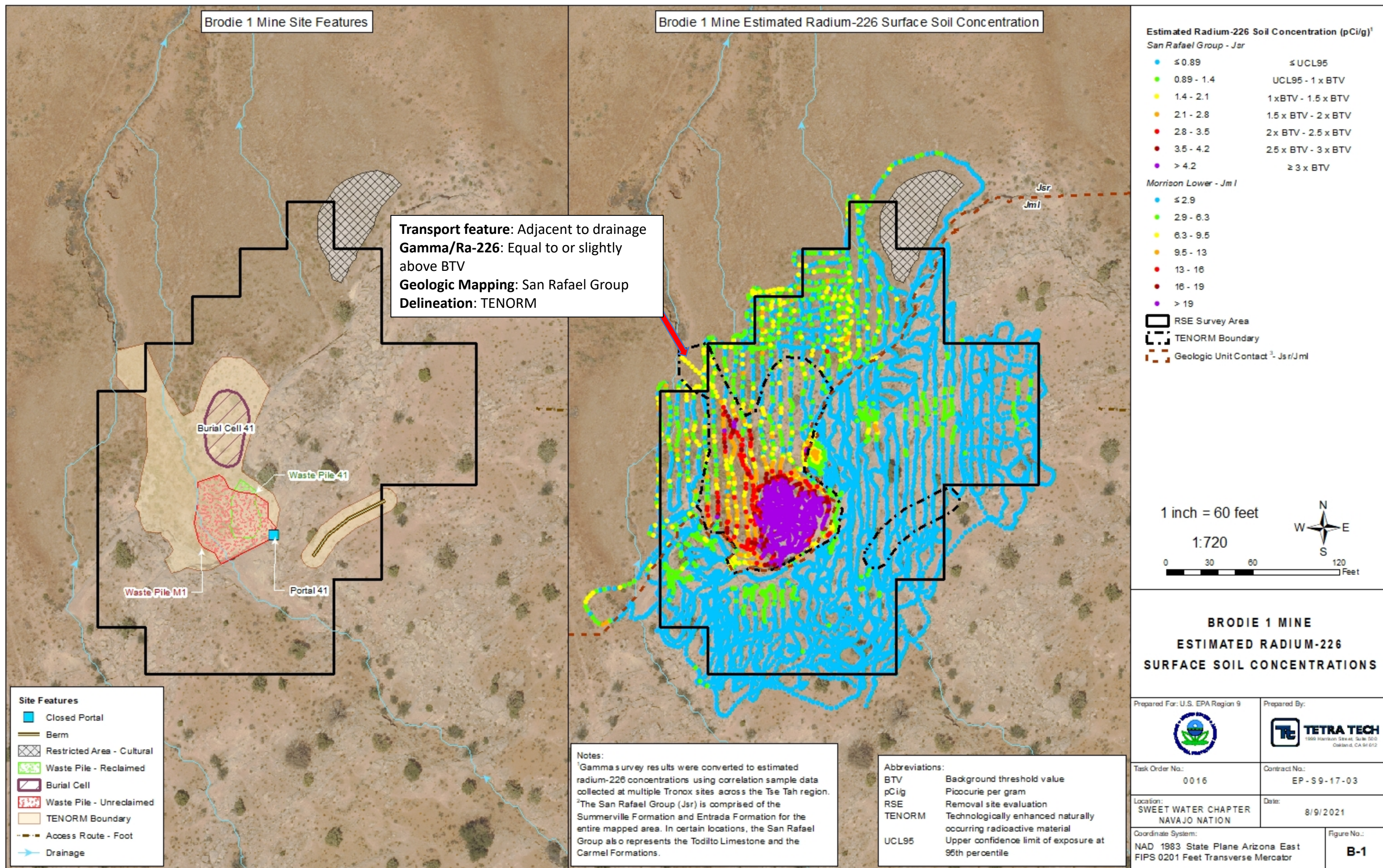
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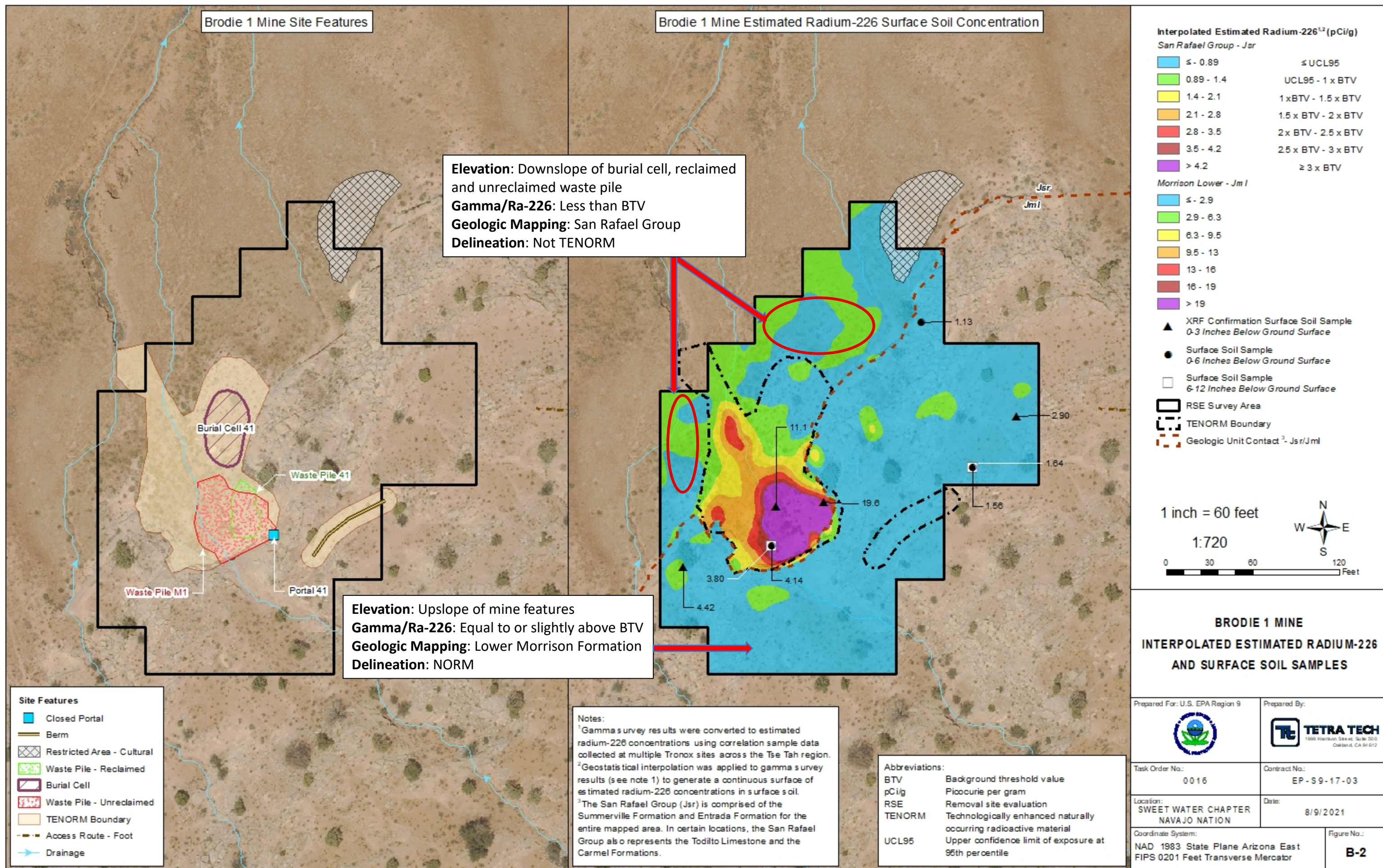
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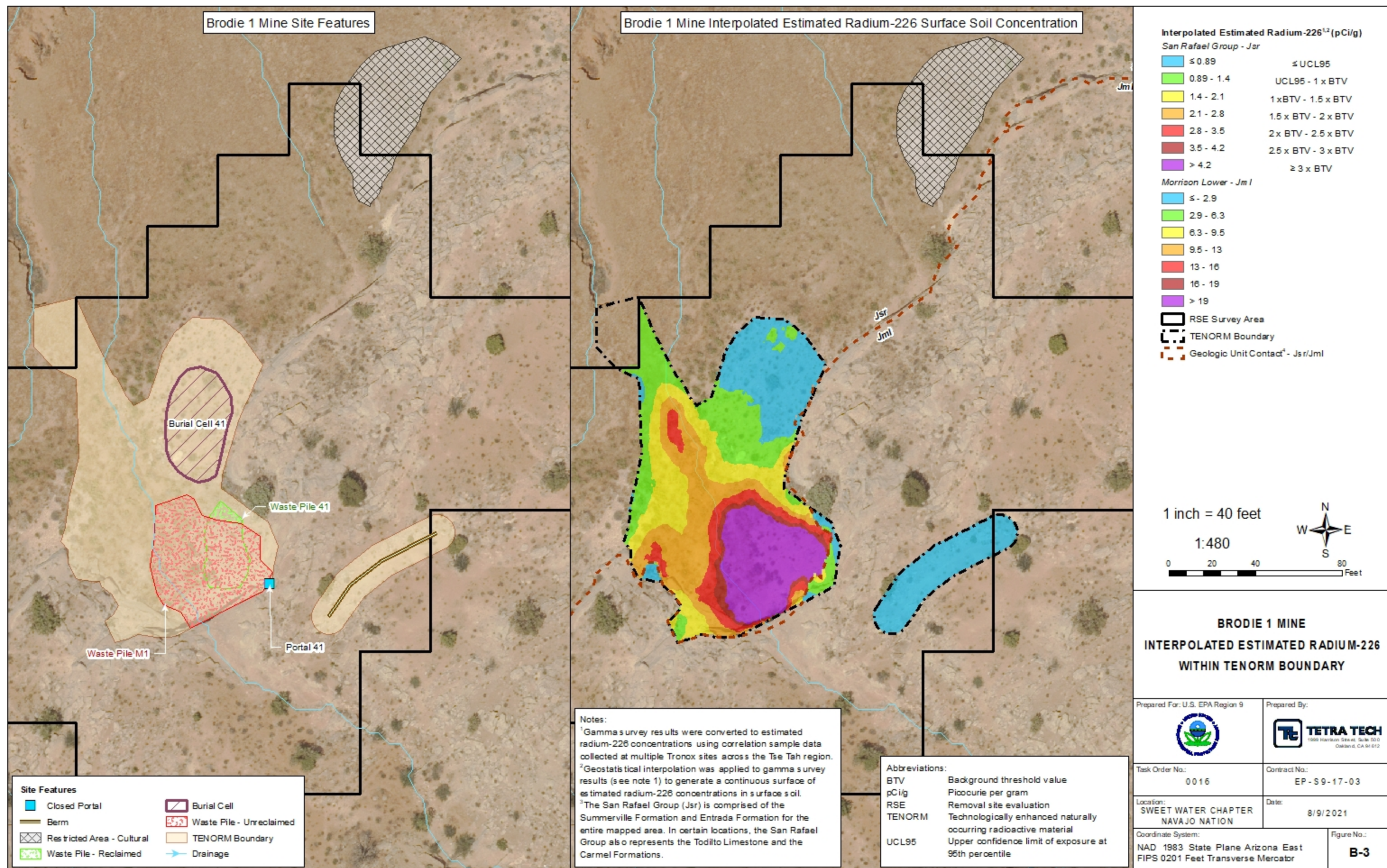
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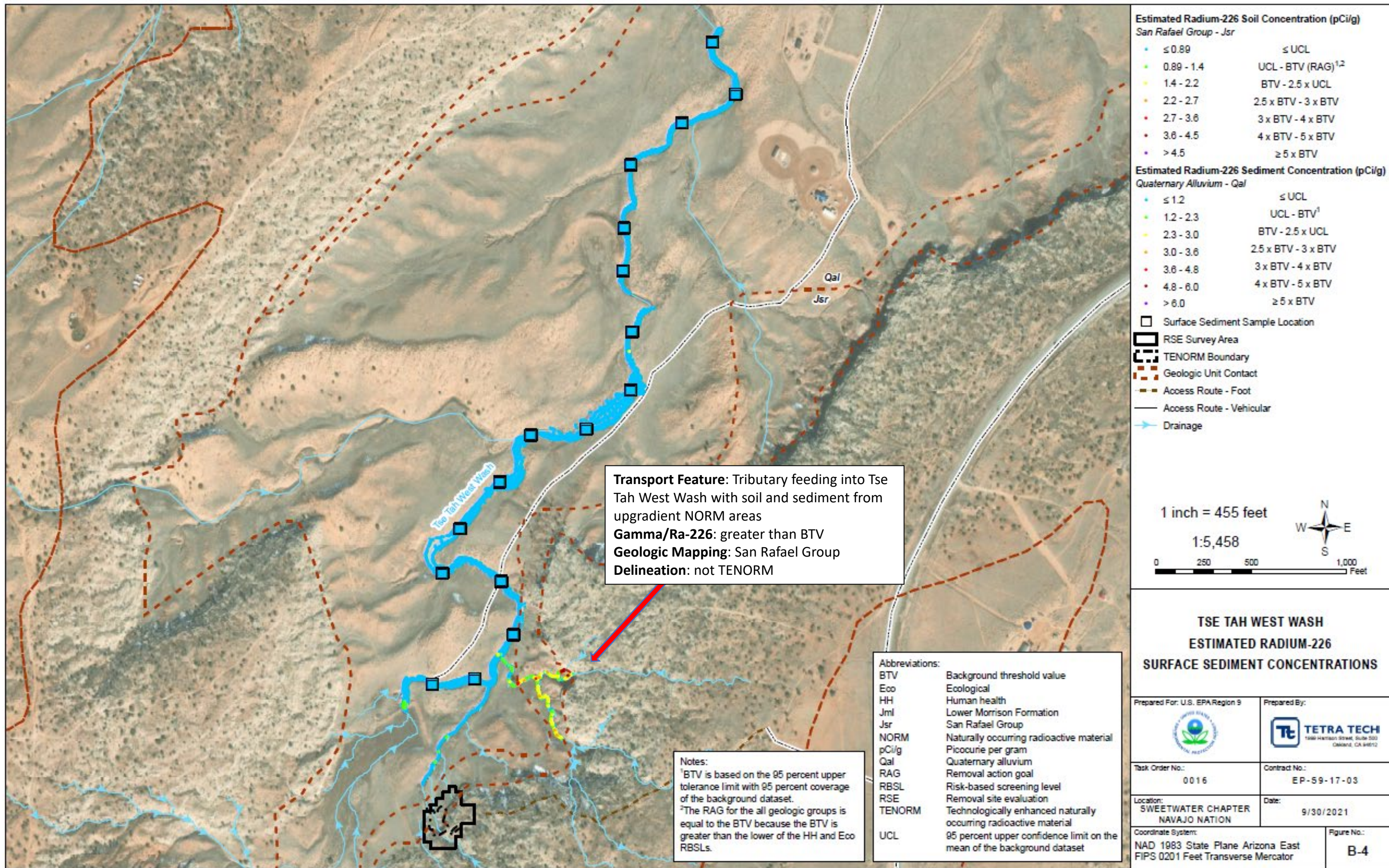
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FIGURES









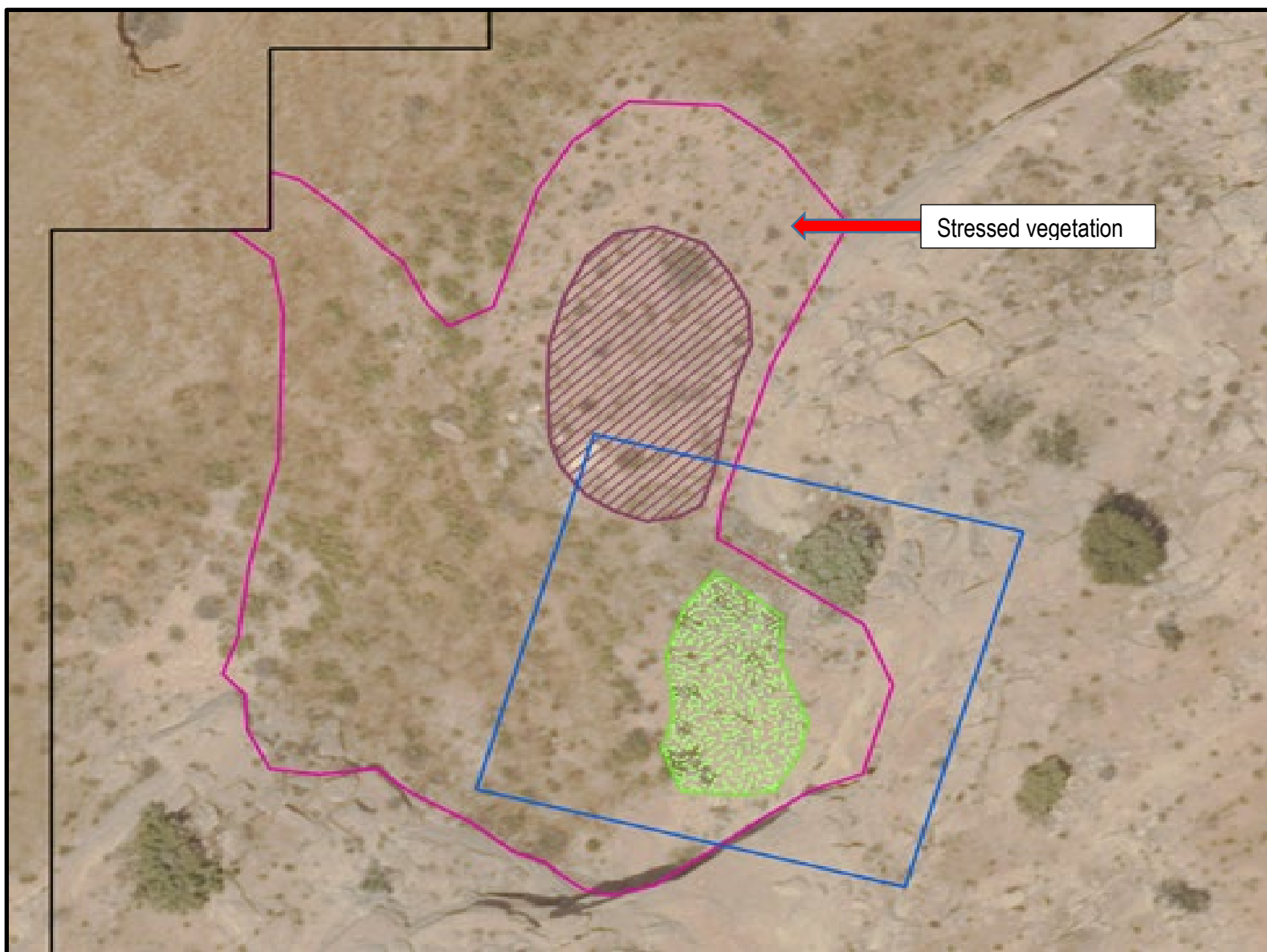


Figure B-5. Aerial Image of Disturbed Land around Burial Cell

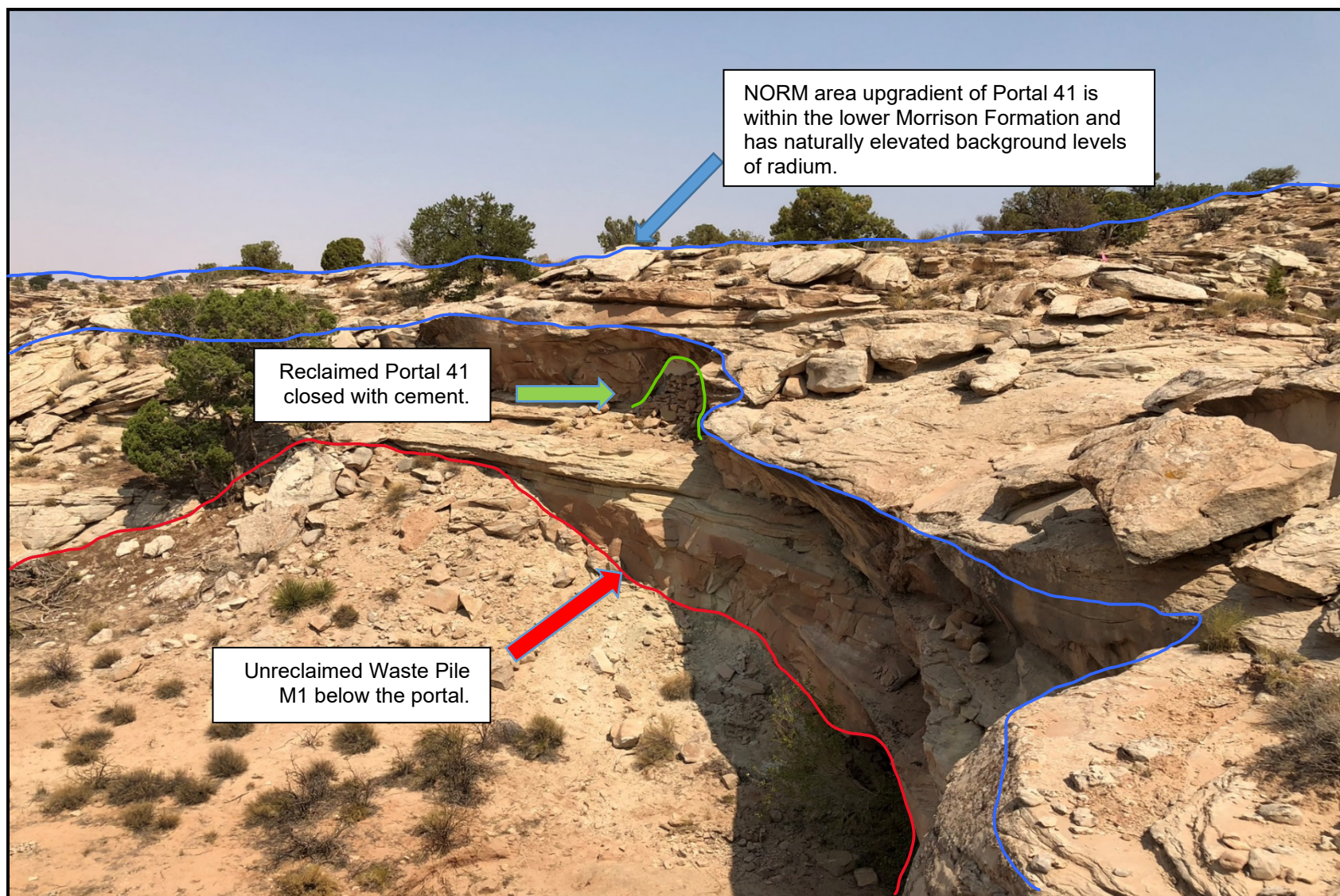


Figure B-6. Brodie 1 Mine NORM and TENORM Areas

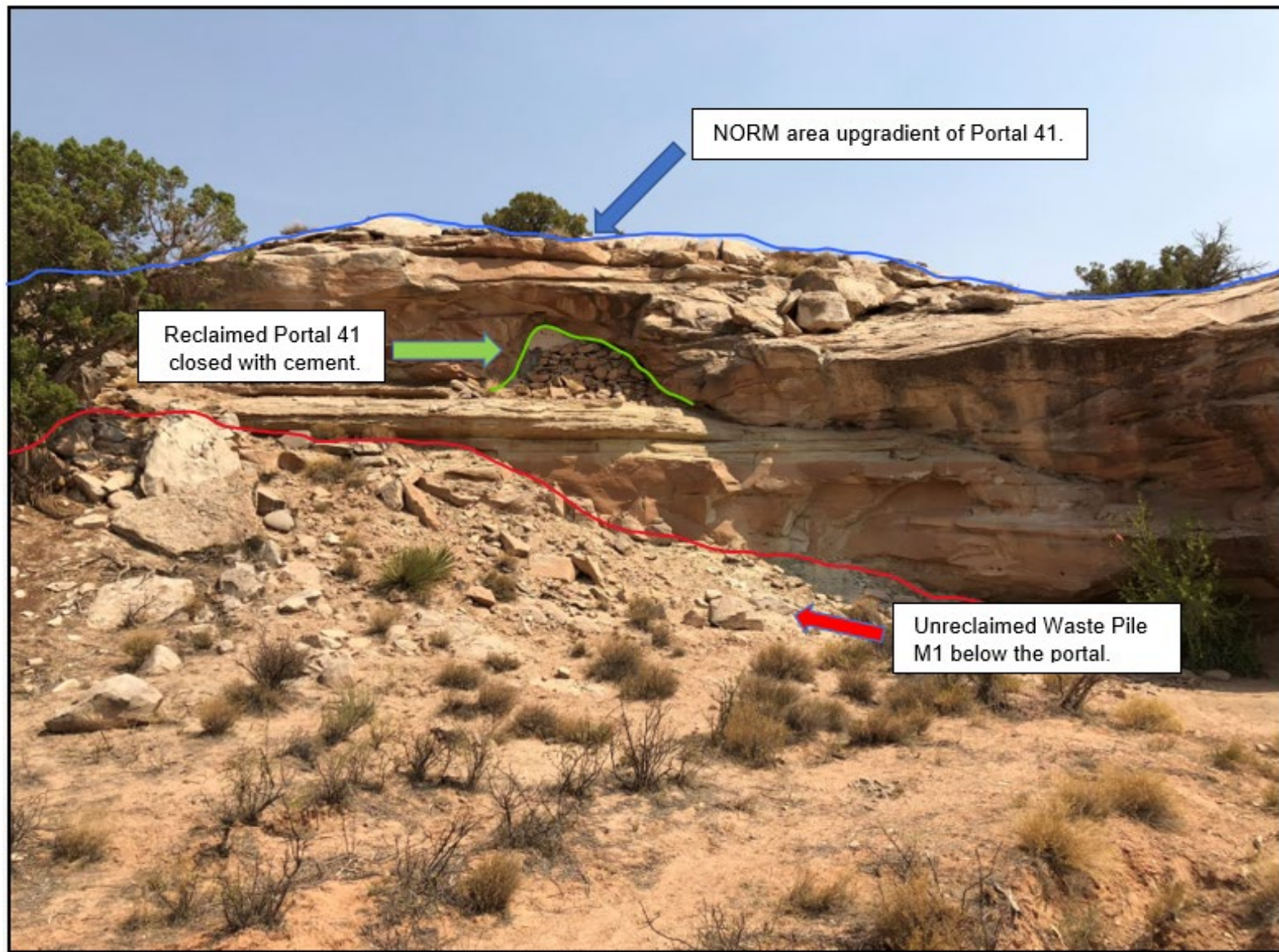


Figure B-7. Brodie 1 Mine NORM and TENORM Areas near Portal 41



Figure B-8. Brodie 1 Mine Reclaimed Portal 41

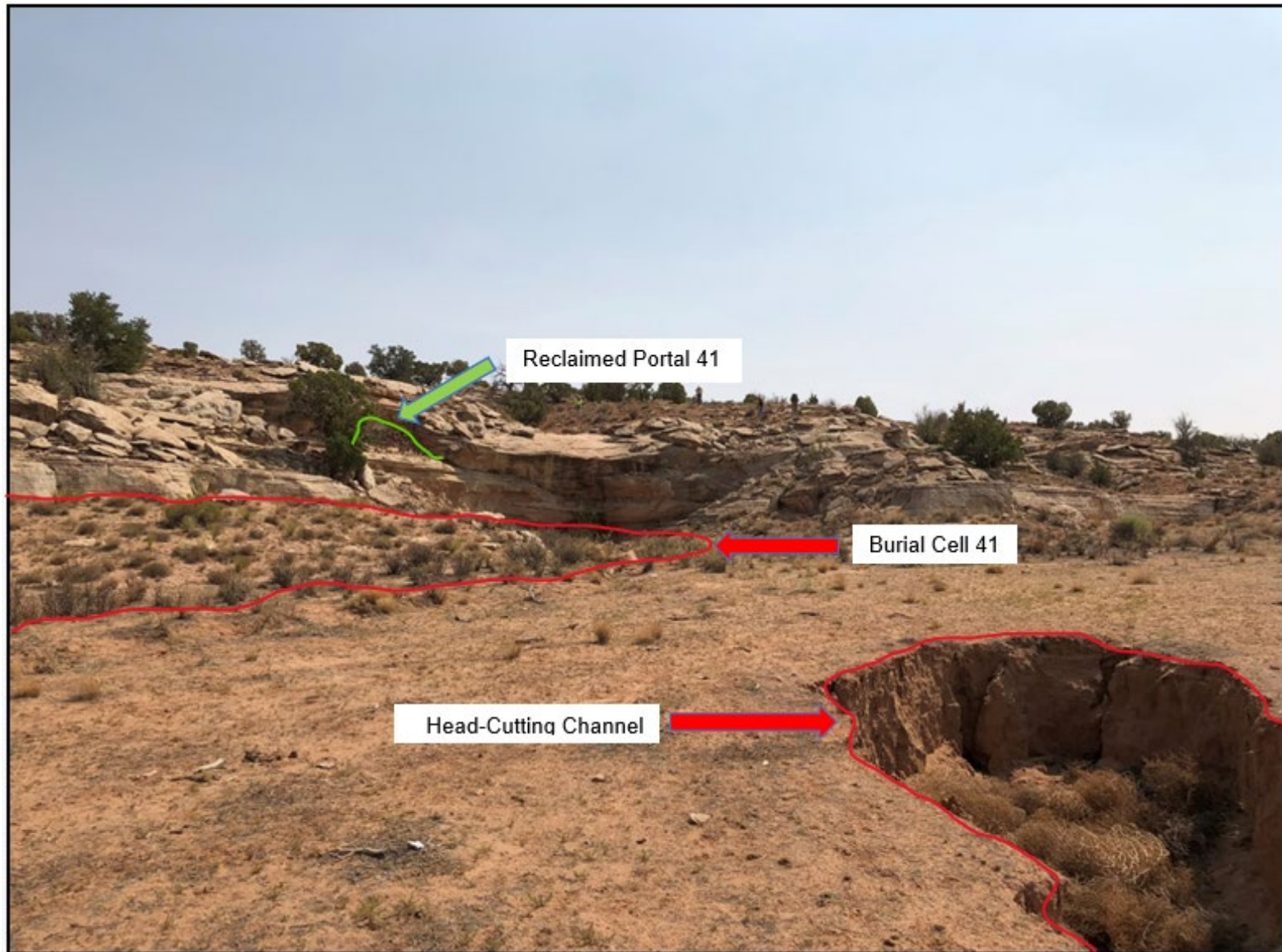


Figure B-9. Brodie 1 Mine Burial Cell 41 and Nearby Features

APPENDIX C

DATA TABLES

Table C-1. Soil Sample Results in Exposure Unit 1 within the San Rafael Group at Brodie 1 Mine

Table C-2. Soil Sample Results in Exposure Unit 2 within the Lower Morrison Formation at Brodie 1 Mine

Table C-3. Sediment Sample Results in Exposure Unit 3 within the Quaternary Alluvium in Tse Tash West Wash

Table C-1. Soil Sample Results in Exposure Unit 1 within the San Rafael Group at Brodie 1 Mine

Exposure Unit	Geology	Mine	Analyte	Sample ID	Sample Date	Sample Top Depth (inches bgs)	Sample Bottom Depth (inches bgs)	Result	Qualifier	TPU	Units	Latitude	Longitude
1	San Rafael Group	Brodie 1 Mine	Arsenic	M1X16	5/13/2018	0	1	2.98			mg/kg	36.906055	-109.352823
1	San Rafael Group	Brodie 1 Mine	Arsenic	M1X17	5/12/2018	0	1	1.80	QU		mg/kg	36.906075	-109.35274
1	San Rafael Group	Brodie 1 Mine	Arsenic	M1X18	5/12/2018	0	1	1.80	QU		mg/kg	36.906073	-109.352614
1	San Rafael Group	Brodie 1 Mine	Arsenic	M1X23	5/13/2018	0	1	1.80	QU		mg/kg	36.905969	-109.352816
1	San Rafael Group	Brodie 1 Mine	Arsenic	M1X24	5/12/2018	0	1	1.80	QU		mg/kg	36.905967	-109.352713
1	San Rafael Group	Brodie 1 Mine	Arsenic	M1X30	5/13/2018	0	1	1.80	QU		mg/kg	36.905876	-109.352815
1	San Rafael Group	Brodie 1 Mine	Arsenic	M1-XS31-01-051218	5/12/2018	0	3	1.70			mg/kg	36.905885	-109.352719
1	San Rafael Group	Brodie 1 Mine	Arsenic	M1-XS32-01-051218	5/12/2018	0	3	1.20			mg/kg	36.905892	-109.352606
1	San Rafael Group	Brodie 1 Mine	Arsenic	M1X35	5/13/2018	0	1	1.80	QU		mg/kg	36.905787	-109.352822
1	San Rafael Group	Brodie 1 Mine	Arsenic	M1-SS36-01-091618	9/16/2018	0	6	1.20			mg/kg	36.905809	-109.352731
1	San Rafael Group	Brodie 1 Mine	Arsenic	M1X36	5/12/2018	0	1	1.80	QU		mg/kg	36.9058	-109.352718
1	San Rafael Group	Brodie 1 Mine	Arsenic	M1-SB36-0612-01-091618	9/16/2018	6	12	3.60			mg/kg	36.905809	-109.352731
1	San Rafael Group	Brodie 1 Mine	Arsenic	M1X37	5/13/2018	0	1	1.80	QU		mg/kg	36.905798	-109.352647
1	San Rafael Group	Brodie 1 Mine	Ra-226	M1-XS31-01-051218	5/12/2018	0	3	11.1		1.3	pCi/g	36.905885	-109.352719
1	San Rafael Group	Brodie 1 Mine	Ra-226	M1-XS32-01-051218	5/12/2018	0	3	19.6		2.4	pCi/g	36.905892	-109.352606
1	San Rafael Group	Brodie 1 Mine	Ra-226	M1-SS36-01-091618	9/16/2018	0	6	3.80		0.57	pCi/g	36.905809	-109.352731
1	San Rafael Group	Brodie 1 Mine	Ra-226	M1-SB36-0612-01-091618	9/16/2018	6	12	4.14		0.6	pCi/g	36.905809	-109.352731
1	San Rafael Group	Brodie 1 Mine	Selenium	M1-XS31-01-051218	5/12/2018	0	3	0.37	J		mg/kg	36.905885	-109.352719
1	San Rafael Group	Brodie 1 Mine	Selenium	M1-XS32-01-051218	5/12/2018	0	3	0.39	J		mg/kg	36.905892	-109.352606
1	San Rafael Group	Brodie 1 Mine	Selenium	M1-SS36-01-091618	9/16/2018	0	6	0.36	J		mg/kg	36.905809	-109.352731
1	San Rafael Group	Brodie 1 Mine	Selenium	M1-SB36-0612-01-091618	9/16/2018	6	12	0.48	J		mg/kg	36.905809	-109.352731
1	San Rafael Group	Brodie 1 Mine	Uranium	M1X16	5/13/2018	0	1	2.92			mg/kg	36.906055	-109.352823
1	San Rafael Group	Brodie 1 Mine	Uranium	M1X17	5/12/2018	0	1	0.080	QU		mg/kg	36.906075	-109.35274
1	San Rafael Group	Brodie 1 Mine	Uranium	M1X18	5/12/2018	0	1	0.080	QU		mg/kg	36.906073	-109.352614
1	San Rafael Group	Brodie 1 Mine	Uranium	M1X23	5/13/2018	0	1	0.080	QU		mg/kg	36.905969	-109.352816
1	San Rafael Group	Brodie 1 Mine	Uranium	M1X24	5/12/2018	0	1	1.03			mg/kg	36.905967	-109.352713
1	San Rafael Group	Brodie 1 Mine	Uranium	M1X30	5/13/2018	0	1	1.95			mg/kg	36.905876	-109.352815
1	San Rafael Group	Brodie 1 Mine	Uranium	M1-XS31-01-051218	5/12/2018	0	3	38.0			mg/kg	36.905885	-109.352719
1	San Rafael Group	Brodie 1 Mine	Uranium	M1-XS32-01-051218	5/12/2018	0	3	19.0			mg/kg	36.905892	-109.352606
1	San Rafael Group	Brodie 1 Mine	Uranium	M1X35	5/13/2018	0	1	3.08			mg/kg	36.905787	-109.352822
1	San Rafael Group	Brodie 1 Mine	Uranium	M1-SS36-01-091618	9/16/2018	0	6	6.00			mg/kg	36.905809	-109.352731
1	San Rafael Group	Brodie 1 Mine	Uranium	M1X36	5/12/2018	0	1	2.87			mg/kg	36.9058	-109.352718
1	San Rafael Group	Brodie 1 Mine	Uranium	M1-SB36-0612-01-091618	9/16/2018	6	12	460			mg/kg	36.905809	-109.352731
1	San Rafael Group	Brodie 1 Mine	Uranium	M1X37	5/13/2018	0	1	2.78			mg/kg	36.905798	-109.352647
1	San Rafael Group	Brodie 1 Mine	Vanadium	M1X16	5/13/2018	0	1	41.1			mg/kg	36.906055	-109.352823
1	San Rafael Group	Brodie 1 Mine	Vanadium	M1X17	5/12/2018	0	1	27.7			mg/kg	36.906075	-109.35274
1	San Rafael Group	Brodie 1 Mine	Vanadium	M1X18	5/12/2018	0	1	20.5			mg/kg	36.906073	-109.352614
1	San Rafael Group	Brodie 1 Mine	Vanadium	M1X23	5/13/2018	0	1	16.0	QU		mg/kg	36.905969	-109.352816
1	San Rafael Group	Brodie 1 Mine	Vanadium	M1X24	5/12/2018	0	1	63.8			mg/kg	36.905967	-109.352713
1	San Rafael Group	Brodie 1 Mine	Vanadium	M1X30	5/13/2018	0	1	42.3			mg/kg	36.905876	-109.352815
1	San Rafael Group	Brodie 1 Mine	Vanadium	M1-XS31-01-051218	5/12/2018	0	3	170			mg/kg	36.905885	-109.352719
1	San Rafael Group	Brodie 1 Mine	Vanadium	M1-XS32-01-051218	5/12/2018	0	3	150			mg/kg	36.905892	-109.352606
1	San Rafael Group	Brodie 1 Mine	Vanadium	M1X35	5/13/2018	0	1	42.0			mg/kg	36.905787	-109.352822
1	San Rafael Group	Brodie 1 Mine	Vanadium	M1-SS36-01-091618	9/16/2018	0	6	36.0			mg/kg	36.905809	-109.352731
1	San Rafael Group	Brodie 1 Mine	Vanadium	M1X36	5/12/2018	0	1	41.3			mg/kg	36.9058	-109.352718
1	San Rafael Group	Brodie 1 Mine	Vanadium	M1-SB36-0612-01-091618	9/16/2018	6	12	150			mg/kg	36.905809	-109.352731
1	San Rafael Group	Brodie 1 Mine	Vanadium	M1X37	5/13/2018	0	1	63.6			mg/kg	36.905798	-109.352647

Table C-1. Soil Sample Results in Exposure Unit 1 within the San Rafael Group at Brodie 1 Mine

Notes:

Data used in exposure point concentration calculations are presented.

bgs	Below ground surface
J	Estimated value
MDL	Method detection limit
mg/kg	Milligram per kilogram
pCi/g	Picocurie per gram
QU	Qualifier is given to a reported value where the XRF reported value is detected but is less than XRFMIN and also less than XRF0. This result is nondetect and reported as the maximum observed laboratory MDL for that analyte.
Ra-226	Radium-226
TPU	Total propagated uncertainty
XRF	X-ray fluorescence
XRF0	XRF value that would equal a laboratory concentration of zero.
XRFMIN	Minimum XRF value used in the development of the correlation for the given analyte.

Table C-2. Soil Sample Results in Exposure Unit 2 within the Lower Morrison Formation at Brodie 1 Mine

Exposure Unit	Geology	Mine	Analyte	Sample ID	Sample Date	Sample Top Depth (inches bgs)	Sample Bottom Depth (inches bgs)	Result	Qualifier	TPU	Units	Latitude	Longitude
2	Morrison Lower	Brodie 1 Mine	Arsenic	M1X34	5/13/2018	0	1	3.77			mg/kg	36.905876	-109.352362
2	Morrison Lower	Brodie 1 Mine	Uranium	M1X34	5/13/2018	0	1	3.02			mg/kg	36.905876	-109.352362
2	Morrison Lower	Brodie 1 Mine	Vanadium	M1X34	5/13/2018	0	1	16.0	QU		mg/kg	36.905876	-109.352362
2	Morrison Lower	Brodie 1 Mine	Arsenic	M1X38	5/13/2018	0	1	8.95			mg/kg	36.905792	-109.352489
2	Morrison Lower	Brodie 1 Mine	Uranium	M1X38	5/13/2018	0	1	4.62			mg/kg	36.905792	-109.352489
2	Morrison Lower	Brodie 1 Mine	Vanadium	M1X38	5/13/2018	0	1	16.0	QU		mg/kg	36.905792	-109.352489

Notes:

Data used in exposure point concentration calculations are presented.

bgs Below ground surface

MDL Method detection limit

mg/kg Milligram per kilogram

QU Qualifier is given to a reported value where the XRF reported value is detected but is less than XRFMIN and also less than XRF0. This result is nondetect and reported as the maximum observed laboratory MDL for that analyte.

TPU Total propagated uncertainty

XRF X-ray fluorescence

XRF0 XRF value that would equal a laboratory concentration of zero.

XRFMIN Minimum XRF value used in the development of the correlation for the given analyte.

Table C-3. Sediment Sample Results in Exposure Unit 3 within the Quaternary Alluvium in Tse Tash West Wash

Exposure Unit	Geology	Mine	Analyte	Sample ID	Sample Date	Sample Top Depth (inches bgs)	Sample Bottom Depth (inches bgs)	Result	Qualifier	TPU	Units	Latitude	Longitude
3	Quaternary Alluvium	Tse Tah West Wash	Arsenic	DM1-SD1-01-081918	8/19/2018	0	6	0.94			mg/kg	36.917174	-109.347685
3	Quaternary Alluvium	Tse Tah West Wash	Arsenic	DM1-SD10-01-081918	8/19/2018	0	6	0.79			mg/kg	36.911523	-109.351014
3	Quaternary Alluvium	Tse Tah West Wash	Arsenic	DM1-SD11-01-081918	8/19/2018	0	6	0.98			mg/kg	36.91085	-109.351586
3	Quaternary Alluvium	Tse Tah West Wash	Arsenic	DM1-SD12-01-081918	8/19/2018	0	6	0.80			mg/kg	36.91018	-109.352306
3	Quaternary Alluvium	Tse Tah West Wash	Arsenic	DM1-SD13-01-081918	8/19/2018	0	6	0.59			mg/kg	36.909539	-109.352631
3	Quaternary Alluvium	Tse Tah West Wash	Arsenic	DM1-SD14-01-081918	8/19/2018	0	6	1.00			mg/kg	36.909413	-109.351569
3	Quaternary Alluvium	Tse Tah West Wash	Arsenic	DM1-SD15-01-081918	8/19/2018	0	6	0.75			mg/kg	36.908642	-109.351362
3	Quaternary Alluvium	Tse Tah West Wash	Arsenic	DM1-SD16-01-081918	8/19/2018	0	6	1.30			mg/kg	36.908008	-109.352071
3	Quaternary Alluvium	Tse Tah West Wash	Arsenic	DM1-SD17-01-081918	8/19/2018	0	6	0.93			mg/kg	36.907935	-109.352825
3	Quaternary Alluvium	Tse Tah West Wash	Arsenic	DM1-SD2-01-081918	8/19/2018	0	6	0.99			mg/kg	36.916415	-109.34728
3	Quaternary Alluvium	Tse Tah West Wash	Arsenic	DM1-SD3-01-081918	8/19/2018	0	6	0.92			mg/kg	36.91601	-109.348248
3	Quaternary Alluvium	Tse Tah West Wash	Arsenic	DM1-SD4-01-081918	8/19/2018	0	6	0.71			mg/kg	36.915415	-109.349181
3	Quaternary Alluvium	Tse Tah West Wash	Arsenic	DM1-SD5-01-081918	8/19/2018	0	6	1.10			mg/kg	36.914501	-109.349306
3	Quaternary Alluvium	Tse Tah West Wash	Arsenic	DM1-SD6-01-081918	8/19/2018	0	6	0.73			mg/kg	36.913884	-109.349337
3	Quaternary Alluvium	Tse Tah West Wash	Arsenic	DM1-SD7-01-081918	8/19/2018	0	6	0.65			mg/kg	36.913001	-109.349178
3	Quaternary Alluvium	Tse Tah West Wash	Arsenic	DM1-SD8-01-081918	8/19/2018	0	6	0.71			mg/kg	36.912159	-109.349215
3	Quaternary Alluvium	Tse Tah West Wash	Arsenic	DM1-SD9-01-081918	8/19/2018	0	6	0.61			mg/kg	36.911603	-109.35002
3	Quaternary Alluvium	Tse Tah West Wash	Ra-226	DM1-SD1-02-081918	8/19/2018	0	6	0.60	LT	0.18	pCi/g	36.917174	-109.347685
3	Quaternary Alluvium	Tse Tah West Wash	Ra-226	DM1-SD10-01-081918	8/19/2018	0	6	0.49	LT	0.19	pCi/g	36.911523	-109.351014
3	Quaternary Alluvium	Tse Tah West Wash	Ra-226	DM1-SD11-01-081918	8/19/2018	0	6	0.60	LT	0.15	pCi/g	36.91085	-109.351586
3	Quaternary Alluvium	Tse Tah West Wash	Ra-226	DM1-SD12-01-081918	8/19/2018	0	6	0.63	UJ	0.24	pCi/g	36.91018	-109.352306
3	Quaternary Alluvium	Tse Tah West Wash	Ra-226	DM1-SD13-01-081918	8/19/2018	0	6	0.50	J-	0.16	pCi/g	36.909539	-109.352631
3	Quaternary Alluvium	Tse Tah West Wash	Ra-226	DM1-SD14-01-081918	8/19/2018	0	6	0.98	J-	0.21	pCi/g	36.909413	-109.351569
3	Quaternary Alluvium	Tse Tah West Wash	Ra-226	DM1-SD15-01-081918	8/19/2018	0	6	0.42	J-	0.15	pCi/g	36.908642	-109.351362
3	Quaternary Alluvium	Tse Tah West Wash	Ra-226	DM1-SD16-01-081918	8/19/2018	0	6	0.47	J-	0.14	pCi/g	36.908008	-109.352071
3	Quaternary Alluvium	Tse Tah West Wash	Ra-226	DM1-SD17-01-081918	8/19/2018	0	6	0.39	J-	0.17	pCi/g	36.907935	-109.352825
3	Quaternary Alluvium	Tse Tah West Wash	Ra-226	DM1-SD2-01-081918	8/19/2018	0	6	0.66	UJ	0.24	pCi/g	36.916415	-109.34728
3	Quaternary Alluvium	Tse Tah West Wash	Ra-226	DM1-SD3-01-081918	8/19/2018	0	6	0.49	LT	0.19	pCi/g	36.91601	-109.348248
3	Quaternary Alluvium	Tse Tah West Wash	Ra-226	DM1-SD4-01-081918	8/19/2018	0	6	0.64	J-	0.21	pCi/g	36.915415	-109.349181
3	Quaternary Alluvium	Tse Tah West Wash	Ra-226	DM1-SD5-01-081918	8/19/2018	0	6	0.57	LT	0.17	pCi/g	36.914501	-109.349306
3	Quaternary Alluvium	Tse Tah West Wash	Ra-226	DM1-SD6-01-081918	8/19/2018	0	6	0.42	J-	0.15	pCi/g	36.913884	-109.349337
3	Quaternary Alluvium	Tse Tah West Wash	Ra-226	DM1-SD7-01-081918	8/19/2018	0	6	0.41	J-	0.14	pCi/g	36.913001	-109.349178
3	Quaternary Alluvium	Tse Tah West Wash	Ra-226	DM1-SD8-01-081918	8/19/2018	0	6	0.50	J-	0.15	pCi/g	36.912159	-109.349215
3	Quaternary Alluvium	Tse Tah West Wash	Ra-226	DM1-SD9-01-081918	8/19/2018	0	6	0.26	UJ	0.16	pCi/g	36.911603	-109.35002
3	Quaternary Alluvium	Tse Tah West Wash	Selenium	DM1-SD1-01-081918	8/19/2018	0	6	0.99	U		mg/kg	36.917174	-109.347685
3	Quaternary Alluvium	Tse Tah West Wash	Selenium	DM1-SD10-01-081918	8/19/2018	0	6	0.97	U		mg/kg	36.911523	-109.351014
3	Quaternary Alluvium	Tse Tah West Wash	Selenium	DM1-SD11-01-081918	8/19/2018	0	6	1.00	U		mg/kg	36.91085	-109.351586
3	Quaternary Alluvium	Tse Tah West Wash	Selenium	DM1-SD12-01-081918	8/19/2018	0	6	0.95	U		mg/kg	36.91018	-109.352306
3	Quaternary Alluvium	Tse Tah West Wash	Selenium	DM1-SD13-01-081918	8/19/2018	0	6	0.99	U		mg/kg	36.909539	-109.352631
3	Quaternary Alluvium	Tse Tah West Wash	Selenium	DM1-SD14-01-081918	8/19/2018	0	6	0.97	U		mg/kg	36.909413	-109.351569
3	Quaternary Alluvium	Tse Tah West Wash	Selenium	DM1-SD15-01-081918	8/19/2018	0	6	0.96	U		mg/kg	36.908642	-109.351362
3	Quaternary Alluvium	Tse Tah West Wash	Selenium	DM1-SD16-01-081918	8/19/2018	0	6	0.94	U		mg/kg	36.908008	-109.352071
3	Quaternary Alluvium	Tse Tah West Wash	Selenium	DM1-SD17-01-081918	8/19/2018	0	6	0.99	U		mg/kg	36.907935	-109.352825
3	Quaternary Alluvium	Tse Tah West Wash	Selenium	DM1-SD2-01-081918	8/19/2018	0	6	0.97	U		mg/kg	36.916415	-109.34728
3	Quaternary Alluvium	Tse Tah West Wash	Selenium	DM1-SD3-01-081918	8/19/2018	0	6	0.93	U		mg/kg	36.91601	-109.348248
3	Quaternary Alluvium	Tse Tah West Wash	Selenium	DM1-SD4-01-081918	8/19/2018	0	6	0.94	U		mg/kg	36.915415	-109.349181
3	Quaternary Alluvium	Tse Tah West Wash	Selenium	DM1-SD5-01-081918	8/19/2018	0	6	0.96	U		mg/kg	36.914501	-109.349306
3	Quaternary Alluvium	Tse Tah West Wash	Selenium	DM1-SD6-01-081918	8/19/2018	0	6	0.97	U		mg/kg	36.913884	-109.349337

Table C-3. Sediment Sample Results in Exposure Unit 3 within the Quaternary Alluvium in Tse Tash West Wash

Exposure Unit	Geology	Mine	Analyte	Sample ID	Sample Date	Sample Top Depth (inches bgs)	Sample Bottom Depth (inches bgs)	Result	Qualifier	TPU	Units	Latitude	Longitude
3	Quaternary Alluvium	Tse Tah West Wash	Selenium	DM1-SD7-01-081918	8/19/2018	0	6	0.99	U		mg/kg	36.913001	-109.349178
3	Quaternary Alluvium	Tse Tah West Wash	Selenium	DM1-SD8-01-081918	8/19/2018	0	6	0.98	U		mg/kg	36.912159	-109.349215
3	Quaternary Alluvium	Tse Tah West Wash	Selenium	DM1-SD9-01-081918	8/19/2018	0	6	0.95	U		mg/kg	36.911603	-109.35002
3	Quaternary Alluvium	Tse Tah West Wash	Uranium	DM1-SD1-02-081918	8/19/2018	0	6	0.52			mg/kg	36.917174	-109.347685
3	Quaternary Alluvium	Tse Tah West Wash	Uranium	DM1-SD10-01-081918	8/19/2018	0	6	0.47			mg/kg	36.911523	-109.351014
3	Quaternary Alluvium	Tse Tah West Wash	Uranium	DM1-SD11-01-081918	8/19/2018	0	6	0.62			mg/kg	36.91085	-109.351586
3	Quaternary Alluvium	Tse Tah West Wash	Uranium	DM1-SD12-01-081918	8/19/2018	0	6	0.42			mg/kg	36.91018	-109.352306
3	Quaternary Alluvium	Tse Tah West Wash	Uranium	DM1-SD13-01-081918	8/19/2018	0	6	0.39			mg/kg	36.909539	-109.352631
3	Quaternary Alluvium	Tse Tah West Wash	Uranium	DM1-SD14-01-081918	8/19/2018	0	6	0.68			mg/kg	36.909413	-109.351569
3	Quaternary Alluvium	Tse Tah West Wash	Uranium	DM1-SD15-01-081918	8/19/2018	0	6	0.47			mg/kg	36.908642	-109.351362
3	Quaternary Alluvium	Tse Tah West Wash	Uranium	DM1-SD16-01-081918	8/19/2018	0	6	0.39			mg/kg	36.908008	-109.352071
3	Quaternary Alluvium	Tse Tah West Wash	Uranium	DM1-SD17-01-081918	8/19/2018	0	6	0.30			mg/kg	36.907935	-109.352825
3	Quaternary Alluvium	Tse Tah West Wash	Uranium	DM1-SD2-01-081918	8/19/2018	0	6	0.70			mg/kg	36.916415	-109.34728
3	Quaternary Alluvium	Tse Tah West Wash	Uranium	DM1-SD3-01-081918	8/19/2018	0	6	0.56			mg/kg	36.91601	-109.348248
3	Quaternary Alluvium	Tse Tah West Wash	Uranium	DM1-SD4-01-081918	8/19/2018	0	6	0.51			mg/kg	36.915415	-109.349181
3	Quaternary Alluvium	Tse Tah West Wash	Uranium	DM1-SD5-01-081918	8/19/2018	0	6	0.42			mg/kg	36.914501	-109.349306
3	Quaternary Alluvium	Tse Tah West Wash	Uranium	DM1-SD6-01-081918	8/19/2018	0	6	0.31			mg/kg	36.913884	-109.349337
3	Quaternary Alluvium	Tse Tah West Wash	Uranium	DM1-SD7-01-081918	8/19/2018	0	6	0.46			mg/kg	36.913001	-109.349178
3	Quaternary Alluvium	Tse Tah West Wash	Uranium	DM1-SD8-01-081918	8/19/2018	0	6	0.49			mg/kg	36.912159	-109.349215
3	Quaternary Alluvium	Tse Tah West Wash	Uranium	DM1-SD9-01-081918	8/19/2018	0	6	0.36			mg/kg	36.911603	-109.35002
3	Quaternary Alluvium	Tse Tah West Wash	Vanadium	DM1-SD1-01-081918	8/19/2018	0	6	4.10			mg/kg	36.917174	-109.347685
3	Quaternary Alluvium	Tse Tah West Wash	Vanadium	DM1-SD10-01-081918	8/19/2018	0	6	4.30			mg/kg	36.911523	-109.351014
3	Quaternary Alluvium	Tse Tah West Wash	Vanadium	DM1-SD11-01-081918	8/19/2018	0	6	4.40			mg/kg	36.91085	-109.351586
3	Quaternary Alluvium	Tse Tah West Wash	Vanadium	DM1-SD12-01-081918	8/19/2018	0	6	3.40			mg/kg	36.91018	-109.352306
3	Quaternary Alluvium	Tse Tah West Wash	Vanadium	DM1-SD13-01-081918	8/19/2018	0	6	3.20			mg/kg	36.909539	-109.352631
3	Quaternary Alluvium	Tse Tah West Wash	Vanadium	DM1-SD14-01-081918	8/19/2018	0	6	5.50			mg/kg	36.909413	-109.351569
3	Quaternary Alluvium	Tse Tah West Wash	Vanadium	DM1-SD15-01-081918	8/19/2018	0	6	3.30			mg/kg	36.908642	-109.351362
3	Quaternary Alluvium	Tse Tah West Wash	Vanadium	DM1-SD16-01-081918	8/19/2018	0	6	4.30			mg/kg	36.908008	-109.352071
3	Quaternary Alluvium	Tse Tah West Wash	Vanadium	DM1-SD17-01-081918	8/19/2018	0	6	4.00			mg/kg	36.907935	-109.352825
3	Quaternary Alluvium	Tse Tah West Wash	Vanadium	DM1-SD2-01-081918	8/19/2018	0	6	4.40			mg/kg	36.916415	-109.34728
3	Quaternary Alluvium	Tse Tah West Wash	Vanadium	DM1-SD3-01-081918	8/19/2018	0	6	4.60			mg/kg	36.91601	-109.348248
3	Quaternary Alluvium	Tse Tah West Wash	Vanadium	DM1-SD4-01-081918	8/19/2018	0	6	3.70			mg/kg	36.915415	-109.349181
3	Quaternary Alluvium	Tse Tah West Wash	Vanadium	DM1-SD5-01-081918	8/19/2018	0	6	4.80			mg/kg	36.914501	-109.349306
3	Quaternary Alluvium	Tse Tah West Wash	Vanadium	DM1-SD6-01-081918	8/19/2018	0	6	3.00			mg/kg	36.913884	-109.349337
3	Quaternary Alluvium	Tse Tah West Wash	Vanadium	DM1-SD7-01-081918	8/19/2018	0	6	3.50			mg/kg	36.913001	-109.349178
3	Quaternary Alluvium	Tse Tah West Wash	Vanadium	DM1-SD8-01-081918	8/19/2018	0	6	4.00			mg/kg	36.912159	-109.349215
3	Quaternary Alluvium	Tse Tah West Wash	Vanadium	DM1-SD9-01-081918	8/19/2018	0	6	3.50			mg/kg	36.911603	-109.35002

Notes:

Data used in exposure point concentration calculations are presented.

bgs Below ground surface

J- Estimated value, may be biased low.

LT Result less than requested minimum detectable concentration, but greater than sample-specific minimum detectable concentration.

mg/kg Milligram per kilogram

pCi/g Picocurie per gram

Ra-226 Radium-226

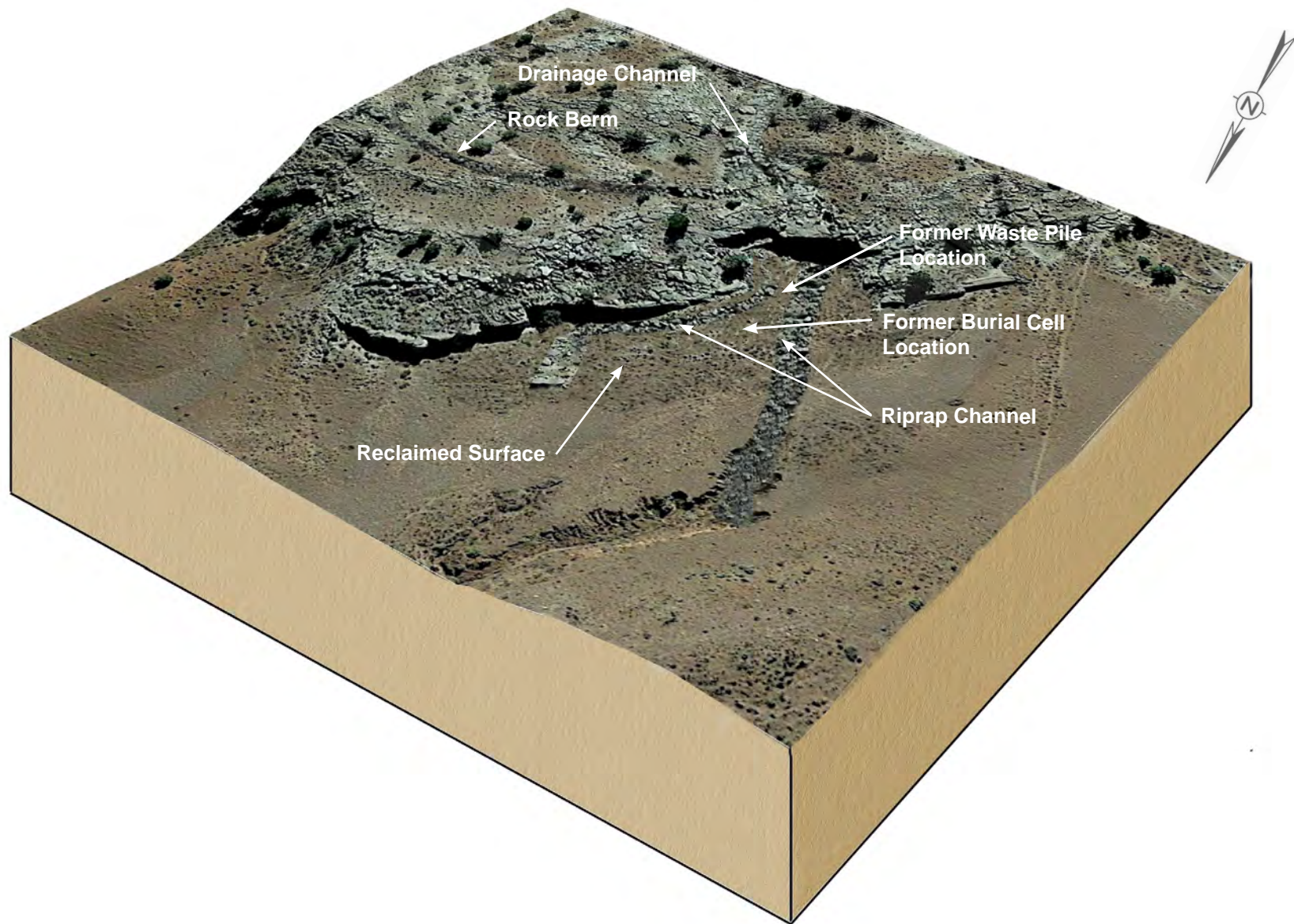
TPU Total propagated uncertainty

U Not detected. The associated value is the reporting limit.

UJ Not considered detected. The associated value is the reported concentration, which is estimated.

APPENDIX D

POST-REMOVAL VISUALIZATIONS



BRODIE 1 MINE POST-RESTORATION

Prepared for: U.S. EPA Region 9



Prepared by:



TETRA TECH

BRODIE 1 MINE POST-RESTORATION VISUALIZATION

Task Order No.:

0016

Contract No:

EP-S9-17-03

Location.:

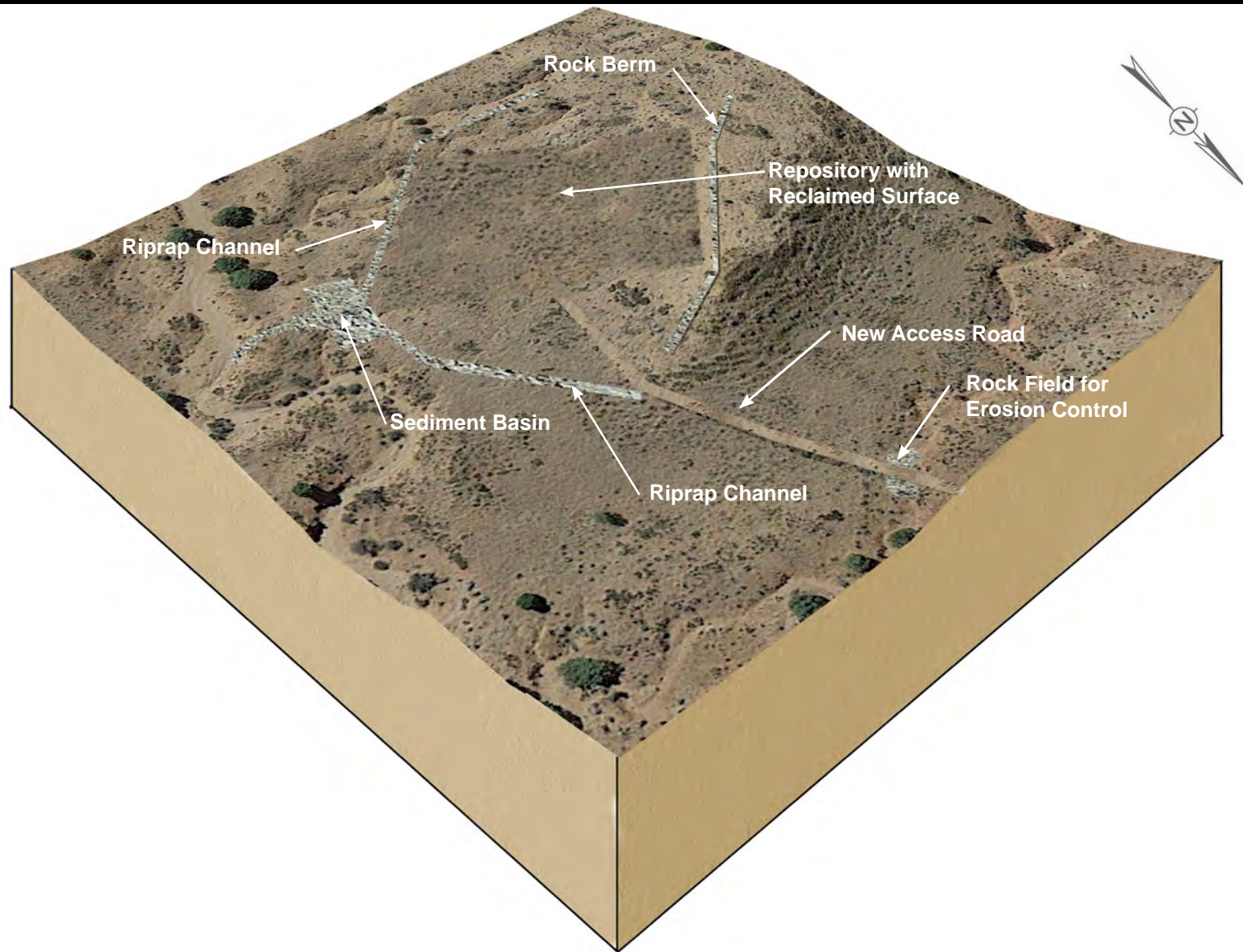
SWEETWATER CHAPTER NAVAJO NATION

Date:

930/2021

Figure No:

D-1



TSE TAH REPOSITORY POST-RESTORATION

Prepared for: U.S. EPA Region 9



Prepared by:



TETRA TECH

**TSE TAH REPOSITORY
POST-RESTORATION VISUALIZATION**

Task Order No.:

0016

Contract No:

EP-S9-17-03

Location.:

SWEETWATER CHAPTER NAVAJO NATION

Date:

9/21/2021

Figure No:

D-2

APPENDIX E

COST ANALYSIS

Tronox Navajo Area Uranium Mines Northern Abandoned Uranium Mine Region

Appendix E: Cost Analysis

Brodie 1 Mine Alternatives Analysis Memorandum

Response, Assessment, and Evaluation Services

Contract No. EP-S9-17-03

Task Order 0016

September 30, 2021

Submitted to

U.S. Environmental Protection Agency

Submitted by

Tetra Tech, Inc.

1999 Harrison Street, Suite 500

Oakland, CA 94612



TABLES

Table E-1. Brodie 1 Mine Comparison of Costs for Each Alternative

Table E-2. Brodie 1 Mine, Cost Rollup for Alternative 2

Table E-3. Brodie 1 Mine, Cost Rollup for Alternative 3

Table E-4. Brodie 1 Mine, Cost Rollup for Alternative 4

Table E-5. Brodie 1 Mine, Cost Rollup for Alternative 5

Table E-6. Brodie 1 Mine, Cost Estimate Scenario Assumptions for Alternative 2, Consolidation and Capping

Table E-7. Brodie 1 Mine, Crew Time Productivity Calculations for Alternative 2, Consolidation and Capping

Table E-8. Brodie 1 Mine, Equipment Cost Details for Alternative 2, Consolidation and Capping

Table E-9. Brodie 1 Mine, Burial Cell Cost Details for Alternative 2, Consolidation and Capping

Table E-10. Brodie 1 Mine, Cost Estimate Details for Alternative 2, Consolidation and Capping

Table E-11. Brodie 1 Mine, Cost Estimate Summary for Alternative 2, Consolidation and Capping

Table E-12. Brodie 1 Mine, Cost Estimate Scenario Assumptions for Alternative 3, Disposal in On-Navajo Nation Regional Repository

Table E-13. Brodie 1 Mine, Crew Time Productivity Calculations for Alternative 3, Disposal in On-Navajo Nation Regional Repository

Table E-14. Brodie 1 Mine, Equipment Cost Details for Alternative 3, Disposal in On-Navajo Nation Regional Repository

Table E-15. Brodie 1 Mine, Regional Repository Cost Details for Alternative 3, Disposal in On-Navajo Nation Regional Repository

Table E-16. Brodie 1 Mine, Cost Estimate Details for Alternative 3, Disposal in On-Navajo Nation Regional Repository

Table E-17. Brodie 1 Mine, Cost Estimate Summary for Alternative 3, Disposal in On-Navajo Nation Regional Repository

Table E-18. Brodie 1 Mine, Cost Estimate Scenario Assumptions for Alternative 4, Off-Navajo Nation Disposal at White Mesa Mill

Table E-19. Brodie 1 Mine, Crew Time Productivity Calculations for Alternative 4, Off-Navajo Nation Disposal at White Mesa Mill

Table E-20. Brodie 1 Mine, Equipment Cost Details for Alternative 4, Off-Navajo Nation Disposal at White Mesa Mill

Table E-21. Brodie 1 Mine, Cost Estimate Details for Alternative 4, Off-Navajo Nation Disposal at White Mesa Mill

Table E-22. Brodie 1 Mine, Cost Estimate Summary for Alternative 4, Off-Navajo Nation Disposal at White Mesa Mill

Table E-23. Brodie 1 Mine, Cost Estimate Scenario Assumptions for Alternative 5, Off-Navajo Nation Disposal at Clean Harbors RCRA C Hazardous Waste Disposal Facility

Table E-24. Brodie 1 Mine, Crew Time Productivity Calculations for Alternative 5, Off-Navajo Nation Disposal at Clean Harbors RCRA C Hazardous Waste Disposal Facility

Table E-25. Brodie 1 Mine, Equipment Cost Details for Alternative 5, Off-Navajo Nation Disposal at Clean Harbors RCRA C Hazardous Waste Disposal Facility

Table E-26. Brodie 1 Mine, Cost Estimate Details for Alternative 5, Off-Navajo Nation Disposal at Clean Harbors RCRA C Hazardous Waste Disposal Facility

Table E-27. Brodie 1 Mine, Cost Estimate Summary for Alternative 5, Off-Navajo Nation Disposal at Clean Harbors RCRA C Hazardous Waste Disposal Facility

TABLES

Table E-1. Brodie 1 Mine Comparison of Costs for Each Alternative

Brodie 1 Mine	Capital Cost	O&M Yearly Cost (10 Years)	O&M Yearly Cost (1000 Years)	Net Present Value (3.5%)
Alternative 2	\$2,240,257	\$24,646	\$22,899	\$3,099,496
Alternative 3	\$2,030,876	\$24,646	\$16,349	\$2,703,132
Alternative 4	\$2,058,075	\$24,646	--	\$2,263,058
Alternative 5	\$2,597,122	\$24,646	--	\$2,802,105

Notes:

O&M

Operation & Maintenance

Table E-2. Brodie 1 Mine, Cost Rollup for Alternative 2

Cost Component	Brodie 1 Mine
Excavated Surface Area (SF)	9,702
Excavated Volume (CY)	1,310
Capital Costs	
Site Access	\$84,931
Waste Excavation	\$11,418
Site Restoration	\$141,648
Burial Cell Construction	\$700,601
Other Construction	\$0
Subtotal Construction	\$938,599
Non-Construction	\$1,301,658
Total Capital Costs	\$2,240,257
O&M Costs	
Annual Site Restoration (10 years)	\$24,646
Annual Access Road Maintenance (1,000 years)	\$13,140
Annual Burial Cell Cap Maintenance (1,000 years)	\$9,759
Total Annual O&M Costs	\$47,545
NPV Costs	
10-Year Site Restoration	\$204,983
1,000 Year Access Road Maintenance	\$375,423
1,000 Year Burial Cell Maintenance	\$278,834
Total NPV Costs	\$3,099,496

Notes:

CY

NPV

O&M

SF

Cubic yard

Net present value

Operation and Maintenance

Square foot

Table E-3. Brodie 1 Mine, Cost Rollup for Alternative 3

Cost Component	Brodie 1 Mine
Excavated Surface Area (SF)	9,702
Excavated Volume (CY)	1,310
Capital Costs	
Site Access	\$90,795
Waste Excavation and Hauling	\$57,090
Site Restoration	\$141,648
Haul Road Restoration	\$121,674
Repository Construction (shared)	\$240,287
Other Construction	\$0
Subtotal Construction	\$651,494
Non-Construction	\$1,379,381
Total Capital Costs	\$2,030,875
O&M Costs	
Annual Site Restoration (10 years)	\$24,646
Annual Access Road Maintenance (1,000 years)	\$13,140
Annual Burial Cell Cap Maintenance (1,000 years)	\$3,209
Total Annual O&M Costs	\$40,995
NPV Costs	
10-Year Site Restoration	\$204,983
1,000 Year Access Road Maintenance	\$375,423
1,000 Year Burial Cell Maintenance	\$91,850
Total NPV Costs	\$2,703,132

Notes:

CY

NPV

O&M

SF

Cubic yard

Net present value

Operation and Maintenance

Square foot

Table E-4. Brodie 1 Mine, Cost Rollup for Alternative 4

Cost Component	Brodie 1 Mine
Excavated Surface Area (SF)	9,702
Excavated Volume (CY)	1,310
Capital Costs	
Site Access	\$84,931
Waste Excavation and Loading	\$32,442
Site Restoration	\$141,648
Haul Road Restoration	\$121,674
Waste Hauling to White Mesa Mill	\$37,139
Disposal at White Mesa Mill	\$132,638
Subtotal Construction	\$550,472
Non-Construction	\$1,507,603
Total Capital Costs	\$2,058,075
O&M Costs	
Annual Site Restoration (10 years)	\$24,646
Total Annual O&M Costs	\$24,646
NPV Costs	
10-Year Site Restoration	\$204,983
Total NPV Costs	\$2,263,058

Notes:

CY

NPV

O&M

SF

Cubic yard

Net present value

Operation and Maintenance

Square foot

Table E-5. Brodie 1 Mine, Cost Rollup for Alternative 5

Cost Component	Brodie 1 Mine
Excavated Surface Area (SF)	9,702
Excavated Volume (CY)	1,310
Capital Costs	
Site Access	\$84,931
Waste Excavation and Loading	\$97,325
Site Restoration	\$141,648
Haul Road Restoration	\$121,674
Waste Hauling to RCRA C Facility	\$332,085
Disposal at RCRA C Facility	\$171,938
Subtotal Construction	\$550,472
Non-Construction	\$1,647,520
Total Capital Costs	\$2,058,075
O&M Costs	
Annual Site Restoration (10 years)	\$24,646
Total Annual O&M Costs	\$24,646
NPV Costs	
10-Year Site Restoration	\$204,983
Total NPV Costs	\$2,802,105

Notes:

CY

NPV

O&M

SF

Cubic yard

Net present value

Operation and Maintenance

Square foot

**Table E-6. Brodie 1 Mine, Cost Estimate Scenario Assumptions for Alternative 2,
Consolidation and Capping**

Technology	Assumptions	Cost Effects
Excavation Methods	Waste removed by an excavator is assumed to be removed with a large excavator, unless specified	Excavators can operate on steeper terrain than bulldozers and are better at moving waste uphill. Bulldozers cost less to operate. Spider excavators or other specialized equipment are more expensive.
	Any disturbed surface can be restored using grading and erosion controls	Quantities of erosion control materials and grading may be lower than costed
	Land is barren to warrant no clearing or grubbing	Costs of clearing and grubbing are zero
	All waste specified in the risk assessment will be excavated	Volumes of excavated waste may be lower than costed
	The site is accessible to haul trucks and trucks can be easily loaded	Accessing difficult-to-reach mines increase costs.
Soil and Waste Sorting	Mine waste will be sorted based on grain size; rock greater than 3 inches will be segregated	NA
	Mine waste can be sorted within the mine waste footprint	Additional restoration of a separate area would be needed, increasing costs
	Waste can be consolidated into a 6,000 square foot area, which will be graded	Consolidation into a larger area decreases the cost for relocating the waste; however, it increases cost for cover soil
	Mine waste can be processed through the screening plant using an excavator	NA
On-Site Burial Cell	Burial Cell can be built on-site	Greater distance to consolidate/cap increases costs
	Waste can be consolidated into a 6,000 square foot area, which will be graded	Consolidation into a larger area decreases the cost for relocating the waste; however, it increases cost for cover soil
	Access road into site will be maintained for PRSC of the burial cell	Removing the road is cheaper
	A bulldozer will be used to excavate borrow soil	Use of an excavator may increase costs
	One cell will be constructed in the burial cell	Multiple cells will not be required
	ET cap (if chosen) will be 3 feet of soil with a biobarrier and capillary break but no liner	Adding biobarrier, capillary break, or liner will increase costs
	No bottom liner or leachate collection system will be installed	Adding bottom liner or leachate collection system increases costs
	Bulldozer will be used to move borrow soil to form cap	Use of an excavator may increase costs.
	The waste excavation area will require cover soil or amendment	If cover soil or amendments are required, costs will increase.
	PRSC inspection of the mine site will be completed for 10 years. PRSC Inspection of the on-site burial cell will be completed for 1000 years.	More PRSC inspections will increase costs

Notes:

CY Cubic yard
ET Evapotranspiration
NA Not applicable - inherent assumption
PRSC Post-removal site control

**Table E-7. Brodie 1 Mine, Crew Time Productivity Calculations for Alternative 2,
Consolidation and Capping**

	Waste Volume	1,310	CY		
	Removal Area	0.22	AC		
	Lower Road Length	0.98	Mi		
	Upper Road Length	0.6	Mi		
Step	Brodie 1 Haul Road Installation				
1	Action	QTY	Unit	Production CY	Days
	Brodie 1 Lower Haul Road - Excavation	2,875	LCY	1,531	1.9
	Brodie 1 Upper Access Road - Excavation	1,760	LCY	1,531	1.15
	Rock Fields	155	CY	2,652	0.06
				Control Days	3
Step	Brodie 1 Excavation				
2	Action	QTY	Unit	Production CY	Days
		1,638		Control Days	0.4
Step	Brodie 1 Restoration				
3	Action	QTY	Unit	Production Rate	Days
	Clean Borrow Fill	807	CY	5,304	0.2
	Grading	2,236	SY	1.3 Days for 2,222 SY	1.3
	Fertilizer, Seed, Mulch	2,236	SY	1,000	2.2
	Erosion Control - Erosion Control Blanket	980	SY	1,000	1.0
	Erosion Control - Coir Logs/Wattles	240	LF	1,000	0.2
	Gabion Weir	0	SY	60	0.0
	Rock Berms	219	LCY	3,864	0.1
	Rock Fields	650	CY	5,304	0.12
				Control Days	5
Step	Brodie 1 Haul Road Restoration				
4	Action	QTY	Unit	Production Rate	Days
	Fertilizer, Seed, Mulch	0	SY	1,000	0
	Haul Road Reclamation - Haul Fill	0	LCY	5,304	0.0
				Control Days	0
				TOTAL PROJECT DAYS	9
				Slowest Rate Project Days:	9

Notes:

AC
 BCY Bank cubic yard
 CY Cubic yard
 LCY Loose cubic yard
 LF Linear foot
 Mi Mile
 QTY Quantity
 SY Square yard

Table E-8. Brodie 1 Mine, Equipment Cost Details for Alternative 2, Consolidation and Capping

Step	Equipment List	QTY	RSMeans #	RSMeans Description	Unit Cost	Unit	Crew
1	M1 Haul Road Building						
	Excavator 3.5 CY ~ 80K-100K lb.	1	312316420305	3.5 CY Excavator Capacity = 300 CY/hour	\$ 1.78	BCY	B12D
	Dozer D6	1	312213200170	8,100-10,000 SF Grading, Dozer	\$ 1,378.08	each	B10L
			015433204260	Rent Dozer, crawler, torque converter, diesel 200 hp	\$ 15,960	Month	None (Rental)
	Grader 30,000 lb.	1	340113100310	Maintenance grading of roadway, 4 passes, 3.0 MPH	\$ 631.65	Mile	B11L
			015433201910	Rent Grader, Self Propelled, 30,000 lb.	\$ 12,705	Month	None (Rental)
	Excavator - Rock Hammer	1	312316300020	Drilling and blasting rock, open face, under 1500 CY	\$ 19.63	BCY	B47
2	Off-Road Haul Truck	4	312323205110	22 CY, 5 MPH, 15 min wait/lb./unld, 2-mile cycle	\$ 6.32	LCY	B34F
	M1 Excavation						
	Off-Road Haul Truck	2	312323205110	22 CY, 5 MPH, 15 min wait/lb./unld, 2-mile cycle	\$ 6.32	LCY	B34F
	Loader 5cy+	1	312323154080	Common Earth - 5cy bucket, front end loader	\$ 16.30	BCY	B10U
			015433204760	Rent front end loader, articulating, 5.25-5.75 CY 270 HP	\$ 8,478.75	Month	None (Rental)
	Grader 30,000 lb.	1	340113100310	Maintenance grading of roadway, 4 passes, 3.0 MPH	\$ 631.65	Mile	B11L
			015433201910	Rent Grader, Self Propelled, 30,000 lb.	\$ 12,705	Month	None (Rental)
	Excavator 3.5 CY ~ 80K-100K lb.	1	312316420305	3.5 CY Excavator Capacity=300 CY/hour	\$ 1.78	BCY	B12D
3	M1 Reclamation						
	Off-Road Haul Truck	1	312323205110	22 CY, 5 MPH, 15 min wait/lb./unld, 2-mile cycle	\$ 6.32	LCY	B34F
	Loader 5CY+	1	312323154080	Common Earth - 5 CY bucket, front-end loader	\$ 16.30	BCY	B10U
			015433204760	Rent front-end loader, articulating, 5.25-5.75 CY 270 hp	\$ 8,478.75	Month	None (Rental)
	Dozer D6	1	312213200170	8,100-10,000 SF Grading, Dozer	\$ 1,378.08	each	B10L
			015433204260	Rent Dozer, crawler, torque converter, diesel 200 hp	\$ 15,960	Month	None (Rental)

Table E-8. Brodie 1 Mine, Equipment Cost Details for Alternative 2, Consolidation and Capping

	Grader 30,000 lb.	1	340113100310	Maintenance grading of roadway, 4 passes, 3.0 MPH	\$ 631.65	Mile	B11L
			015433201910	Rent Grader, Self Propelled, 30,000 lb.	\$ 12,705	Month	None (Rental)
	Excavator 3.5 CY ~ 80K-100K lb.	1	312316420305	3.5 CY Excavator Capacity = 300 CY/hour	\$ 1.78	BCY	B12D
	Rip Rap Class II 18"-24"	2346.3		Assume \$5/mile Class II within 115 miles = \$575 delivery of 23 tons and Class II Rip-rap at \$20/ton	\$ 45.00	Ton	
4	M1 Haul Road Closure						
	Excavator 3.5 CY ~ 80K-100K lb.	1	312316420305	3.5 CY Excavator Capacity = 300 CY/hour	\$ 1.78	BCY	B12D
	Loader 5CY+	1	312323154080	Common Earth - 5 CY bucket, front-end loader	\$ 16.30	BCY	B10U
			015433204760	Rent front-end loader, articulating, 5.25-5.75 CY 270 hp	\$ 8,478.75	Month	None (Rental)
	Dozer D6	1	312213200170	8,100-10,000 SF Grading, Dozer	\$ 1,378.08	each	B10L
			015433204260	Rent Dozer, crawler, torque converter, diesel 200 hp	\$ 15,960	Month	None (Rental)
	Grader 30,000 lb.	1	340113100310	Maintenance grading of roadway, 4 passes, 3.0 MPH	\$ 631.65	Mile	B11L
			015433201910	Rent Grader, Self Propelled, 30,000 lb.	\$ 12,705	Month	None (Rental)
	Off-Road Haul Truck	1	312323205110	22 CY, 5 MPH, 15 min wait/ld./unld, 2-mile cycle	\$ 6.32	LCY	B34F

Notes:

' Foot
 " Inch
 BCY Bank cubic yard
 CY Cubic yard
 hp Horse power
 K Thousand
 lb. Pound
 LCY Loose cubic yard
 ld. Loaded
 LF Linear foot
 M2 Square meters
 MPH Mile per hour
 psi Pound per square inch
 QTY Quantity
 SF Square feet
 unld. Unloaded
 W Width

**Table E-9. Brodie 1 Mine, Burial Cell and Evapotranspiration Cap Cost Details for Alternative 2,
Consolidation and Capping**

Site Measurements	QTY	Unit	QTY	Unit		
Repository Area	0.12	AC	5,053	SF		
Repository topsoil 3"	47	CY				
Borrow Topsoil 3" (1.5 AC)	605	CY				
Clean Fill Volume (Volume From Estimate calculator)	1,871	CY				
Soil Barrow Fill Volume (at 10' depth need 0.1 AC Area)	-1,215	CY				
Waste Volume	1,310	CY				
Laydown Area (google earth)	1.1	AC	49,658	SF		
Laydown topsoil 3"	460	CY				
Engineering Design	Equipment List	Crew	Unit	Amount	Price	Cost
Project Manager			Hour	0.58	\$ 158	\$ 91
Project Engineer			Hour	2.3	\$ 122	\$ 280
Design Engineer			Hour	1.1	\$ 158	\$ 181
CAD/GIS Operator			Hour	0.6	\$ 102	\$ 59
Admin			Hour	0.23	\$ 67	\$ 15
Reproduction			LS	3.0	\$ 500	\$ 1,500
						\$ 2,127
Site Prep	Equipment List	Crew	Daily	Unit	Days	Cost
Clearing and Grubbing	Mulching EQ	B-65	\$ 1,712.23	1	0.42	\$ 717
Storm Drain Channel Excavation(includes laydown+25%)	Excavator 3.5 CY = 300CY/hr.	B-12D	\$ 3,664.80	1	3.4	\$ 12,369
Storm Drain Channel Armoring (Riprap)(includes laydown and Pond +25%)	Excavator 3.5 CY = 300CY/hr.	B-12D	\$ 3,664.80	1	2.4	\$ 8,768
	Loader 5.5CY	B-10U	\$ 2,032.94	1	2.4	\$ 4,864
						\$ 13,632
Water Berm Construction and Compaction (includes laydown +25%)	Excavator 3.5 CY = 300CY/hr.	B-12D	\$ 3,664.80	1		\$ -
	Vibrating plate, Gas 21"	B-18	\$ 1,796.16	1	3.4	\$ 6,062
	Water Truck	B-59	\$ 1,124.99	1	3.4	\$ 3,797
						\$ 9,859
Storm Drain Pond Excavation (includes laydown +25%)	Excavator 3.5 CY = 300CY/hr.	B-12D	\$ 3,664.80	1	0	\$ -
						\$ 36,576

**Table E-9. Brodie 1 Mine, Burial Cell and Evapotranspiration Cap Cost Details for Alternative 2,
Consolidation and Capping**

Excavation	Equipment List	Crew	Daily	Unit	Days	Cost
Topsoil Stripping and Stockpiling	Excavator 3.5 CY = 300CY/hr.	B-12D	\$ 3,664.80	1	1.1	\$ 4,074
	Off Road Haul Truck	B34F	\$ 1,653.82	3	1.1	\$ 5,515
	Loader 5.5CY	B-10U	\$ 2,032.94	1	1.1	\$ 2,260
	Water Truck	B-59	\$ 1,124.99	1	1.1	\$ 1,251
						\$ 13,099
Repository and Soil Barrow Excavation and Stockpiling	Excavator 3.5 CY = 300CY/hr.	B-12D	\$ 3,664.80	1	0.57	\$ 2,081
	Off Road Haul Truck 22CY	B34F	\$ 1,653.82	2	0.57	\$ 1,879
	Dozer 300 HP	B-10M	\$ 2,931.70	1	0.57	\$ 1,665
	Water Truck	B-59	\$ 1,124.99	1	0.57	\$ 639
						\$ 6,264
Borrow Material Screening	Loader 5.5CY	B-10U	\$ 2,032.94	1	0.57	\$ 1,155
	Screen Plant		\$ 4,725	1	0.57	\$ 2,684
	Water Truck	B-59	\$ 1,124.99	1	0.57	\$ 639
						\$ 4,477
Bottom Grading	30,000 lb. Grader	B-11L	\$ 2,413.50	1	0.57	\$ 1,371
						\$ 25,211
Operation	Equipment List	Crew	Daily	Unit	Days	Cost
Waste Screening	Loader 5.5CY	B-10U	\$ 2,032.94	1	1.1	\$ 2,306
	Screen Plant		\$ 4,725	1	1.1	\$ 5,359
	Off Road Haul Truck	B34F	\$ 1,653.82	3	1.1	\$ 5,627
	Dozer 300 HP	B-10M	\$ 2,931.70	1	1.1	\$ 3,325
	Water Truck	B-59	\$ 1,124.99	1	1.1	\$ 1,276
						\$ 17,893
Waste Grading of Each Lift + Waste Compaction of Each Lift	30,000 lb. Grader	B-32A	\$ 3,856	1	1.1	\$ 4,373
	Water Truck	B-59	\$ 1,124.99	1	1.1	\$ 1,276
						\$ 5,649
						\$ 23,543
Closure	Equipment List	Crew	Daily	Unit	Days	Cost
Waste Final Grading	30,000 lb. Grader	B-11L	\$ 2,413.50	1	3.9	\$ 9,429
	Water Truck	B-59	\$ 1,124.99	1	3.9	\$ 4,395
						\$ 13,824

**Table E-9. Brodie 1 Mine, Burial Cell and Evapotranspiration Cap Cost Details for Alternative 2,
Consolidation and Capping**

Cap Cover Installation	Gravel Delivered - 1" Rock Crushed Size 56 (Tons)		\$ 10.95	12	1	\$ 135
	Gravel Delivered - 5/8" Rock Crushed (Tons)		\$ 18.80	35	1	\$ 660
	Loader 5.5CY	B-10U	\$ 2,032.94	1	3.7	\$ 7,432
	Off Road Haul Truck	B34F	\$ 1,653.82	4	0.7	\$ 4,340
	Dozer 300 HP	B-10M	\$ 2,931.70	1	0.7	\$ 1,923
	30,000 lb. Grader	B-11L	\$ 2,413.50	1	0.7	\$ 1,583
	Water Truck	B-59	\$ 1,124.99	1	0.7	\$ 738
						\$ 16,812
						\$ 30,636
Reclamation	Equipment List	Crew	Unit	Amount	Price	Cost
Revegetation Mat			SF	1,152	\$ 1.68	\$ 1,935
Hay Bales/Wattles and Silt Fence			LF	300	\$ 8.55	\$ 2,565
Fertilizer, Seed, and Mulch			SY	514	\$ 4.02	\$ 2,066
						\$ 6,567
Other Line Items	Equipment List	Crew	Unit	Amount	Price	Cost
Fence			LF	312	\$ 38	\$ 11,856
Survey			AC	0.12	\$ 3,425	\$ 397
Water Well, Pump, Tank and Generator			LS	1	\$ 47,700	\$ 47,700
Well Installation			LS	700	\$ 77	\$ 53,900
						\$ 113,853
Subtotal Construction Costs						\$ 236,386
Contractor Site Overhead						\$ 282,103
Travel + Lodging:						\$ 20,667
Mobilization / Demobilization:						\$ 73,675
Level of Accuracy (20%)						\$ 47,277
Navajo Tax (6%):						\$ 38,366
Total Construction Cost:						\$ 700,601
Yearly Post Removal Site Control (PRSC) Costs						
Site Inspections			1	EA	\$1,000	\$ 1,000
Site Maintenance			1% of Construction Cost			\$ 7,006
Subtotal PRSC Costs						\$ 8,006
PRSC Contingencies			15%			\$ 1,201

**Table E-9. Brodie 1 Mine, Burial Cell and Evapotranspiration Cap Cost Details for Alternative 2,
Consolidation and Capping**

Navajo Tax			6% of PRSC and Contingencies Cost			\$ 552
Total Yearly PRSC Cost						\$ 9,759
Present Value of PRSC Costs Based on 1,000 Year Life at 3.50%			PV Factor = 28.571			\$ 278,834
Total Present Worth						\$ 979,435
Cost Per CY:						\$ 748

Notes:

"	Inch
AC	Acres
CAD	Computer-aided design
CY	Cubic yard
EA	Each
EQ	Equipment
GIS	Geographic information system
hr	Hour
lb.	Pound
LF	Linear feet
LS	Lump sum
N/A	Not applicable
PV	Present value
PRSC	Post-removal site control
SY	Square yard

**Table E-10. Brodie 1 Mine, Cost Estimate Details for Alternative 2,
Consolidation and Capping**

Engineering Design	Crew	Unit	Amount	Price	Cost
Project Manager	N/A	Hour	293	\$ 158	\$ 46,294
Project Engineer	N/A	Hour	1170	\$ 122	\$ 142,740
Design Engineer	N/A	Hour	585	\$ 158	\$ 92,430
CAD/GIS Operator	N/A	Hour	293	\$ 102	\$ 29,886
Admin	N/A	Hour	117	\$ 67	\$ 7,839
Reproduction	N/A	LS	3	\$ 500	\$ 1,500
					\$ 320,689
Planning Documents	Crew	Unit	Amount	Price	Cost
Project Manager	N/A	Hour	405	\$ 158	\$ 63,990
Project Engineer	N/A	Hour	1620	\$ 122	\$ 197,640
CAD/GIS Operator	N/A	Hour	405	\$ 102	\$ 41,310
Admin	N/A	Hour	162	\$ 67	\$ 10,854
Reproduction	N/A	LS	3	\$ 500	\$ 1,500
					\$ 315,294
Resource Surveys	Crew	Unit	Amount	Price	Cost
Cultural Resources Mitigation	N/A	Each	1	\$ 2,366.64	\$ 2,367
Biological Resources Mitigation	N/A	Each	1	\$ 4,733.28	\$ 4,733
Geotechnical Testing and Report	N/A	Each	1	\$ 4,733.28	\$ 4,733
Post-Project Aerial LiDAR Survey	N/A	Each	1	\$ 7,099.92	\$ 7,100
					\$ 18,933
Confirmation Sampling	Crew	Unit	Amount	Price	Cost
Developing Sampling and Analysis Plan					
Project Geologist	N/A	Hour	360	\$ 158.00	\$ 56,880
Project Manager	N/A	Hour	180	\$ 111.00	\$ 19,980
CAD/GIS Operator	N/A	Hour	180	\$ 122.00	\$ 21,960
Project Chemist	N/A	Hour	360	\$ 111.00	\$ 39,960
Health and Safety Manager	N/A	Hour	180	\$ 151.00	\$ 27,180
Admin	N/A	Hour	72	\$ 67.00	\$ 4,824
Reproduction	N/A	LS	3	\$ 250.00	\$ 750
Sampling					
Sampling Team - Staff Geologist	N/A	Hour	7	\$ 77.00	\$ 547
Sampling Team - Staff Engineer	N/A	Hour	7	\$ 81.00	\$ 575
Travel	N/A	Day	2	\$ 170.00	\$ 340
Per Diem (96/55)	N/A	Day	2	\$ 151.00	\$ 302
Miscellaneous Field Supplies and Expenses	N/A	LS	1	\$ 1,209.83	\$ 1,210
Lab Analysis	N/A	LS	1	\$ 389.79	\$ 390
XRF Surveying					
Sampling Team - Staff Geologist	N/A	Hour	27	\$ 77.00	\$ 2,041
Sampling Team - Staff Engineer	N/A	Hour	27	\$ 81.00	\$ 2,147
Travel	N/A	Day	3	\$ 170.00	\$ 510
Per Diem (96/55)	N/A	Day	4	\$ 151.00	\$ 643
Miscellaneous Field Supplies and Expenses	N/A	LS	1	\$ 1,209.83	\$ 1,210
Lab Analysis	N/A	LS	1	\$ 389.79	\$ 390
Frisking Equipment	N/A	Month	2	\$ 144.00	\$ 341
					\$ 182,179

**Table E-10. Brodie 1 Mine, Cost Estimate Details for Alternative 2,
Consolidation and Capping**

Reporting	Crew	Unit	Amount	Price	Cost
Project Geologist	N/A	Hour	316	\$ 105.00	\$ 33,180
Project Manager	N/A	Hour	158	\$ 175.00	\$ 27,650
Project Engineer	N/A	Hour	474	\$ 122.00	\$ 57,828
Chemist	N/A	Hour	158	\$ 111.00	\$ 17,538
CAD/GIS Operator	N/A	Hour	158	\$ 102.00	\$ 16,116
Admin	N/A	Hour	63	\$ 67.00	\$ 4,221
Reproduction	N/A	LS	3	\$ 500.00	\$ 1,500
					\$ 158,033
Mobilization/Demobilization	Crew	Unit	Amount	Price	Cost
Crew Mileage	N/A	Mile	5,040	\$ 0.56	\$ 2,822
Per Diem	N/A	Day	15	\$ 182.00	\$ 2,730
Labor	N/A	Day	15	\$ 300.00	\$ 4,500
Standard Equipment Mileage	N/A	Mile	5,040	\$ 0.56	\$ 2,822
Standard Equipment Rental	N/A	Day	2	\$ 17,657.42	\$ 35,315
					\$ 48,190
Haul Road Building	Crew	Daily	Unit #	Days	Cost
Excavator 3.5 cy ~ 80K-100K lb.	B12D	\$ 3,664.00	1	4	\$ 14,656
Dozer D6	B10M	\$ 2,931.70	1	4	\$ 11,727
Grader 30,000 lb.	B11L	\$ 2,413.50	1	4	\$ 9,654
Water Truck	B45	\$ 889.00	1	4	\$ 3,556
Off Road Haul Truck	B34F	\$ 1,653.82	4	4	\$ 26,461
Rip Rap Class II 18"-24"	NA	\$ 45.00	419.5	1	\$ 18,878
				Total	\$ 84,931
Excavation & Hauling	Crew	Daily	Unit #	Days	Cost
Loader 5cy+	B10U	\$ 2,032.94	1	1	\$ 2,033
Off Road Haul Truck	B34F	\$ 1,653.82	2	1	\$ 3,308
Grader 30,000 lb.	B11L	\$ 2,413.50	1	1	\$ 2,414
Excavator 3.5 cy ~ 80K-100K lb.	B12D	\$ 3,664.00	1	1	\$ 3,664
				Total	\$ 11,418
Reclamation	Crew	Daily	Unit #	Days	Cost
Off Road Haul Truck	B34F	\$ 1,653.82	1	6	\$ 9,923
Loader 5cy+	B10U	\$ 2,032.94	1	1	\$ 2,033
Grader 30,000 lb.	B11L	\$ 2,413.50	1	2	\$ 4,827
Excavator 3.5 cy ~ 80K-100K lb.	B12D	\$ 3,664.00	1	1	\$ 3,664
Dozer D6	B10M	\$ 2,931.70	1	1	\$ 2,932
Rip Rap Class II 18"-24"	NA	\$ 45.00	2346.3	1	\$ 105,584
Mine Area Reclamation Materials	N/A	\$ 68,239.50	1	1	\$ 12,686
				Total	\$ 141,648
Haul Road Reclamation	Crew	Daily	Unit #	Days	Cost
Excavator 3.5 cy ~ 80K-100K lb.	B12D	\$ 3,664.00	1	0	\$ -
Loader 5cy+	B10U	\$ 2,032.94	1	0	\$ -
Dozer D6	B10M	\$ 2,931.70	1	0	\$ -
Grader 30,000 lb.	B11L	\$ 2,413.50	1	0	\$ -
Off Road Haul Truck	B34F	\$ 1,653.82	2	0	\$ -
Haul Road Reclamation Materials	N/A	\$ -	1	0	\$ -
				Total	\$ 122,930

**Table E-10. Brodie 1 Mine, Cost Estimate Details for Alternative 2,
Consolidation and Capping**

Contractor Site Overhead	Crew	Unit	Amount	Price	Cost
Project Manager (10% of time)	N/A	Hour	9	\$ 175.00	\$ 1,504
Site Superintendent	N/A	Hour	86	\$ 191.00	\$ 16,418
H&S Officer	N/A	Hour	86	\$ 85.00	\$ 7,307
QA/QC Officer	N/A	Hour	86	\$ 85.00	\$ 7,307
Field Clerk	N/A	Hour	86	\$ 19.00	\$ 1,633
Fuel for Site Vehicles	N/A	Month	2	\$ 1,600.00	\$ 3,897
Port-o-let Rental (4)	N/A	Month	2	\$ 208.00	\$ 358
Permanent Fencing Installation and Demolition	N/A	LF	567	\$ 41.92	\$ 23,787
Job Trailers (1)	N/A	Month	0	\$ 269.00	\$ 116
Storage Boxes (1)	N/A	Month	0	\$ 94.50	\$ 41
Field Office Lights/HVAC (1)	N/A	Month	0	\$ 179.00	\$ 77
Generator (1)	N/A	Month	1	\$ 2,400.00	\$ 2,063
Fuel for Generator	N/A	Gallons	258	\$ 4.00	\$ 1,032
Telephone/internet (1)	N/A	Month	0	\$ 384.00	\$ 165
Field Office Equipment	N/A	Month	0	\$ 230.00	\$ 99
Field Office Supplies	N/A	Month	0	\$ 96.00	\$ 41
Trash (1 dumpster)	N/A	Month	0	\$ 910.00	\$ 391
Clin 1034 High Volume Air Sampling (4)	N/A	Month	2	\$ 383.00	\$ 658
Clin 1025 Ludlum 2121 and 43-10-1	N/A	Month	0	\$ 275.00	\$ 118
Air Monitoring Lab Confirmation Sampling (5 samples per day)	N/A	Day	43	\$ 600.00	\$ 25,788
Clin 1036 Personal Air Monitor	N/A	Month	6	\$ 204.00	\$ 1,224
Clin 1038 Personal Dust Monitor	N/A	Month	6	\$ 1,555.00	\$ 9,330
Clin 1068 Personal Dosimeter Badge	N/A	Month	6	\$ 59.00	\$ 354
Truck Scales	N/A	Month	0	\$ 300.00	\$ 129
Construction Water (excavation)	N/A	Gallon	3100	\$ 0.05	\$ 155
Construction Water (hauling waste soil plus cap mat'l)	N/A	Gallon	63000	\$ 0.05	\$ 3,150
6,000 Gallon Water Truck and Operator (1)	N/A	Day	9	\$ 889.00	\$ 7,642
Portal Water Tower Trailer, 10,000 gallons (1)	N/A	Day	9	\$ 172.36	\$ 1,482
					\$ 116,264
Third-Party Oversight	Crew	Unit	Amount	Price	Cost
Travel and Lodging (4 people)	N/A	Day	34	\$ 151.00	\$ 5,192
Labor	N/A	Hour	344	\$ 80.00	\$ 27,507
Car Rental (4 cars)	N/A	Month	2	\$ 400.00	\$ 688
Car Fuel	N/A	Month	2	\$ 760.00	\$ 1,307
					\$ 34,693
Level of Accuracy (20%)	Crew	Unit	Amount	Price	Cost
20% of Construction Cost	N/A	N/A	N/A	N/A	\$ 47,600
Navajo Tax (6%)	Crew	Unit	Amount	Price	Cost
6% of Confirmation Sampling, Construction, Contractor Overhead, Mobilization / Demobilization, and Third Party Oversight	N/A	N/A	N/A	N/A	\$ 40,015
			GRAND TOTAL		\$ 1,539,656

**Table E-10. Brodie 1 Mine, Cost Estimate Details for Alternative 2,
Consolidation and Capping**

PRSC Costs	Crew	Unit	Amount	Price	Cost
Bi-annual Inspection (4 person crew, 1 day, 10 hr/day)	N/A	Hour	80	\$ 85.00	\$ 6,800
Mileage (Farmington, NM, to Site, roundtrip)	N/A	Mile	217	\$ 0.58	\$ 126
Inspection Crew Per Diem	N/A	Day	8	\$ 151.00	\$ 1,208
Assumed Annual Maintenance costs (revegetation, grading, watering)	N/A	SY	2,236	\$ 1.11	\$ 2,484
Preperation of Semi-annual Reports (Professional Engineer)	N/A	Hour	80	\$ 120.00	\$ 9,600
PRSC Annual Cost					\$ 20,218
PRSC Contingency (15%)					\$ 3,033
Navajo Tax (6% of PRSC and Contingencies Cost					\$ 1,395
Total PRSC Annual Cost					\$ 24,646
Road PRSC Costs (every 10 years)	Crew	Unit	Amount	Price	Cost
Mileage (Farmington, NM, to Site, roundtrip, 3 vehicles, 3 trips every 10 years)	N/A	Mile	977	\$ 0.06	\$ 57
Construction Crew Per Diem and Labor (9 people, 3 trips every 10 years, 2 extra days to mobilize/demobilize)	N/A	Day	6	\$ 433.80	\$ 2,603
Grader, Loader, Excavator, Dozer, Haul Truck	N/A	Day	6	\$ 1,221.76	\$ 7,331
Gravel (assumed 5% of total area, 750 tons per acre)	N/A	Ton	71.27	\$ 1.80	\$ 128
Riprap Class II (assume 3 tons per 1,000 LF of road)	N/A	Ton	15.52	\$ 5.50	\$ 85
PRSC Annual Cost					\$ 10,204
PRSC Contingency (15%)					\$ 1,531
Navajo Tax (6% of PRSC and Contingencies Cost					\$ 704
Total PRSC Annual Cost					\$ 12,438

Notes:

"

CAD

CY

GIS

H&S

hp

hr

HVAC

K

lb.

LF

LiDAR

LS

M2

N/A

NM

PRSC

QA/QC

SY

XRF

Inch

Computer-aided design

Cubic yard

Geographic information system

Health and safety

Horsepower

Hour

Heating, ventilation, and air conditioning

Thousand

Pound

Linear feet

Light detection and ranging

Lump sum

Square meters

Not applicable

New Mexico

Post-removal site control

Quality assurance/quality control

Square yard

X-ray fluorescence

**Table E-11. Brodie 1 Mine, Cost Estimate Summary for Alternative 2,
Consolidation and Capping**

Waste Volume	1310 CY
Removal Area	0.22 AC
Haul Road Building	Ratio T&M Cost
Excavator 3.5 cy ~ 80K-100K lb.	\$ 14,656
Dozer D6	\$ 11,727
Grader 30,000 lb.	\$ 9,654
Water Truck	\$ 3,556
Off Road Haul Truck	\$ 26,461
Rip Rap Class II 18"-24"	\$ 18,878
Subtotals Step 1	\$ 84,931
Excavation & Hauling	Unit Cost
Heavy Lift Helicopter	\$ -
Support Helicopter	\$ -
Loader 5cy+	\$ 2,033
Off Road Haul Truck	\$ 3,308
Grader 30,000 lb.	\$ 2,414
Excavator 3.5 cy ~ 80K-100K lb.	\$ 3,664
Subtotals Step 2	\$ 11,418
Reclamation	Unit Cost
Off Road Haul Truck	\$ 9,923
Loader 5cy+	\$ 2,033
Grader 30,000 lb.	\$ 4,827
Excavator 3.5 cy ~ 80K-100K lb.	\$ 3,664
Dozer D6	\$ 2,932
Rip Rap Class II 18"-24"	\$ 105,584
Mine Area Reclamation Materials	\$ 12,686
Subtotals Step 3	\$ 141,648
Haul Road Reclamation	Unit Cost
Excavator 3.5 cy ~ 80K-100K lb.	\$ -
Loader 5cy+	\$ -
Dozer D6	\$ -
Grader 30,000 lb.	\$ -
Off Road Haul Truck	\$ -
Haul Road Reclamation Materials	\$ -
Subtotals Step 4	\$ -
Subtotal Construction	\$ 237,998
Other Costs	Unit Cost
Non-Construction Costs	
Engineering Design	\$ 320,689
Planning Documents	\$ 315,294
Resource Surveys	\$ 18,933
Confirmation Sampling	\$ 182,179
Reporting	\$ 158,033
Contractor Site Overhead	\$ 116,264
Mobilization / Demobilization	\$ 48,190
Travel+ Lodging (Construction Workers)	\$ 19,768
Level of Accuracy (20%)	\$ 47,600

**Table E-11. Brodie 1 Mine, Cost Estimate Summary for Alternative 2,
Consolidation and Capping**

Third-Party Oversight	\$	34,693
Navajo Tax (6%)	\$	40,015
Subtotals Step 6	\$	1,301,658
Total Site Capital Costs	\$	1,539,656
Yearly On-Site PRSC Costs	Unit Cost	
Bi-annual Inspection (4 person crew, 3 days, 10 hr/day)	\$	6,800
Mileage (Farmington, NM, to Site, roundtrip)	\$	126
Inspection Crew Per Diem	\$	1,208
Assumed Annual Maintenance costs (revegetation, grading, watering)	\$	2,484
Preperation of Semi-annual Reports (Professional Engineer)	\$	9,600
Subtotal PRSC Costs	\$	20,218
PRSC Contingencies (15%)	\$	3,033
Navajo Tax (6% of PRSC and Contingencies Cost)	\$	1,395
Total Yearly PRSC Costs	\$	24,646
Present Value of PRSC Costs Based on 10-Year Life at 3.50% (PV Factor = 8.317)	\$	204,983
Road PRSC Costs (Every 10 Years)	Unit Cost	
Mileage (Farmington, NM, to Site, roundtrip)	\$	57
Construction Crew Per Diem and Labor (9 people)	\$	2,603
Widen, Grade, Compact Equipment Rental (Grader, Loader, Excavator, Dozer, Haul Truck)	\$	7,331
Gravel (assumed 5% of total area, 750 tons per acre)	\$	474
Riprap Class II (assume 3 tons per 1,000 LF of road)	\$	315
Subtotal PRSC Costs	\$	10,779
PRSC Contingencies (15%)	\$	1,617
Navajo Tax (6% of PRSC and Contingencies Cost)	\$	744
Total Yearly PRSC Costs	\$	13,140
Present Value of PRSC Costs Based on 1,000-Year Life at 3.50% (PV Factor = 28.571)	\$	375,423
Burial Cell ET Cap Cost		
Burial Cell ET Cap Construction Cost	\$	700,601
Burial Cell Total Yearly PRSC Costs	\$	9,759
Burial Cell ET Cap Cost per CY (Construction and 1000-Year PRSC Cost)	\$	748
ET Cap Total Cost	\$	979,435
TOTAL COSTS	\$	3,099,496

Notes:

"

AC

CY

ET

hp

hr

K

lb.

LF

NM

PRSC

PV

T&M

Inch

Acres

Cubic yard

Evapotranspiration

Horsepower

Hour

Thousand

Pound

Linear feet

New Mexico

Post-removal site control

Present value

Time and material

**Table E-12. Brodie 1 Mine, Cost Estimate Scenario Assumptions for Alternative 3,
Disposal in On-Navajo Nation Regional Repository**

Technology	Assumptions	Cost Effects
Excavation Methods	Waste removed by an excavator is assumed to be removed with a large excavator, unless specified	Excavators can operate on steeper terrain than bulldozers and are better at moving waste uphill. Bulldozers cost less to operate. Spider excavators or other specialized equipment are more expensive.
	Any disturbed surface can be restored using grading and erosion controls	Quantities of erosion control materials and grading may be lower than costed
	Land is barren to warrant no clearing or grubbing	Costs of clearing and grubbing are zero
	All waste specified in the risk assessment will be excavated	Volumes of excavated waste may be lower than costed
	The site is accessible to haul trucks and trucks can be easily loaded	Accessing difficult-to-reach mines increase costs.
Soil and Waste Sorting	Mine waste will be sorted based on grain size; rock greater than 3 inches will be segregated	NA
	Mine waste can be sorted within the mine waste footprint	Additional restoration of a separate area would be needed, increasing costs
	Mine waste can be processed through the screening plant using an excavator	NA
Regional Repository	Suitable repository location is available within 6 road miles of the mine waste	Greater distance to repository increases costs
	Waste can be consolidated into a 34,000 square foot repository, which will be graded	Consolidation into a larger area decreases the cost for relocating the waste; however, it increases cost for cover soil
	Repository will be excavated to a depth of 7 feet with borrow soil stockpiled nearby	It is unlikely that an onsite location for a repository with 4 feet of borrow soil will be available, and top soil will likely need to be imported.
	A bulldozer will be used to excavate borrow soil	Use of an excavator may increase costs
	One cell will be constructed in the repository	Multiple cells will be required because of weather conditions and will increase complexity and costs
	Waste will be consolidated from multiple locations	Consolidating waste from multiple locations increases costs
	Waste will be transported in haul trucks	Longer hauling distances will slow production rate of excavation
	ET cap will be 3 feet of soil with a biobarrier and capillary break but no liner	Adding biobarrier, capillary break, or liner will increase costs
	GCL cap (if chosen) will be 2 feet of soil with a biobarrier and liner	Adding biobarrier, capillary break, or liner will increase costs
	No bottom liner or leachate collection system will be installed	Adding bottom liner or leachate collection system increases costs
	Bulldozer will be used to move borrow soil to form cap	Use of an excavator may increase costs.
	The waste excavation area will not require cover soil or amendment	If cover soil or amendments are required, costs will increase.
	PRSC inspection of the mine site will be completed for 10 years. PRSC Inspection of the on-site burial cell will be completed for 1000 years.	More PRSC inspections will increase costs

**Table E-12. Brodie 1 Mine, Cost Estimate Scenario Assumptions for Alternative 3,
Disposal in On-Navajo Nation Regional Repository**

Notes:

CY	Cubic yard
ET	Evapotranspiration
GCL	Geosynthetic clay liner
NA	Not applicable - inherent assumption
PRSC	Post-removal site control

**Table E-13. Brodie 1 Mine, Crew Time Productivity Calculations for Alternative 3,
Disposal in On-Navajo Nation Regional Repository**

	Waste Volume	1,310	CY		
	Removal Area	0.22	AC		
Step	Brodie 1 Haul Road Installation				
1	Action	QTY	Unit	Production CY	Days
	Brodie 1 Lower Haul Road - Excavation	2,875	LCY	1,531	1.9
	Brodie 1 Repository Haul Road - Excavation (assumes 20% required to be widened)	3,706	LCY	1,531	2.4
	Brodie 1 Upper Access Road - Excavation	1,760	LCY	1,531	1.15
	Rock Fields	155	CY	2,652	0.06
				Control Days	6
Step	Brodie 1 Excavation				
2	Action	QTY	Unit	Production CY	Days
	Waste Removal WP M1 and Excavate Drainage - Excavator	1,638	LCY	381	4.3
		1,638		Control Days	4.3
Step	Brodie 1 Restoration				
3	Action	QTY	Unit	Production Rate	Days
	Clean Borrow Fill	807	CY	5,304	0.2
	Grading	2,236	SY	1.3 Days for 2,222 SY	1.3
	Fertilizer, Seed, Mulch	2,236	SY	1,000	2.2
	Erosion Control - Erosion Control Blanket	980	SY	1,000	1.0
	Erosion Control - Coir Logs/Wattles	240	LF	1,000	0.2
	Gabion Weir	0	SY	60	0.0
	Rock Berms	219	LCY	3,864	0.6
	Rock Fields	650	CY	5,304	0.12
				Control Days	6
Step	Brodie 1 Haul Road Restoration				
4	Action	QTY	Unit	Production Rate	Days
	Fertilizer, Seed, Mulch	5,280	SY	1,000	5
	Haul Road Reclamation - Haul Fill	4,635	LCY	5,304	0.9
				Control Days	6
				TOTAL PROJECT DAYS	22
				Slowest Rate Project Days:	22

Notes:

AC
BCY Bank cubic yard
CY Cubic yard
LCY Loose cubic yard
LF Linear foot
Mi Mile
QTY Quantity
SY Square yard

**Table E-14. Brodie 1 Mine, Equipment Cost Details for Alternative 3,
Disposal in On-Navajo Nation Regional Repository**

Step	Equipment List	QTY	RSMeans #	RSMeans Description	Unit Cost	Unit	Crew
1	M1 Haul Road Building						
	Excavator 3.5 CY ~ 80K-100K lb.	1	312316420305	3.5 CY Excavator Capacity = 300 CY/hour	\$1.78	BCY	B12D
	Dozer D6	1	312213200170	8,100-10,000 SF Grading, Dozer	\$1,378.08	each	B10L
			015433204260	Rent Dozer, crawler, torque converter, diesel 200 hp	\$15,960.00	Month	None (Rental)
	Grader 30,000 lb.	1	340113100310	Maintenance grading of roadway, 4 passes, 3.0 MPH	\$631.65	Mile	B11L
			015433201910	Rent Grader, Self Propelled, 30,000 lb.	\$12,705.00	Month	None (Rental)
	Excavator - Rock Hammer	1	312316300020	Drilling and blasting rock, open face, under 1500 CY	\$19.63	BCY	B47
2	Off-Road Haul Truck	4	312323205110	22 CY, 5 MPH, 15 min wait/lb./unld, 2-mile cycle	\$6.32	LCY	B34F
	M1 Excavation						
	Heavy Lift Helicopter	1			\$14,000.00	HR	None
	Support Helicopter	1			\$1,200.00	HR	None
	Spyder EX - 2 cy ~18,000 lb.	1			\$300.00	HR	None
	Drag Line/Winches	1			\$600.00	HR	None
	Off-Road Haul Truck	2	312323205110	22 CY, 5 MPH, 15 min wait/lb./unld, 2-mile cycle	\$6.32	LCY	B34F
	Loader 5cy+	1	312323154080	Common Earth - 5cy bucket, front end loader	\$16.30	BCY	B10U
			015433204760	Rent front end loader, articulating, 5.25-5.75 CY 270 HP	\$8,478.75	Month	None (Rental)
	Grader 30,000 lb.	1	340113100310	Maintenance grading of roadway, 4 passes, 3.0 MPH	\$631.65	Mile	B11L
			015433201910	Rent Grader, Self Propelled, 30,000 lb.	\$12,705.00	Month	None (Rental)
	Excavator 3.5 CY ~ 80K-100K lb.	1	312316420305	3.5 CY Excavator Capacity=300 CY/hour	\$1.78	BCY	B12D
	M1 Reclamation						
	Spyder EX - 2 cy ~18,000 lb.	1			\$300.00	HR	None
	Drag Line	1			\$600.00	HR	None
	Off-Road Haul Truck	1	312323205110	22 CY, 5 MPH, 15 min wait/lb./unld, 2-mile cycle	\$6.32	LCY	B34F

**Table E-14. Brodie 1 Mine, Equipment Cost Details for Alternative 3,
Disposal in On-Navajo Nation Regional Repository**

3	Loader 5CY+	1	312323154080	Common Earth - 5 CY bucket, front-end loader	\$16.30	BCY	B10U
			015433204760	Rent front-end loader, articulating, 5.25-5.75 CY 270 hp	\$8,478.75	Month	None (Rental)
	Dozer D6	1	312213200170	8,100-10,000 SF Grading, Dozer	\$1,378.08	each	B10L
			015433204260	Rent Dozer, crawler, torque converter, diesel 200 hp	\$15,960.00	Month	None (Rental)
	Grader 30,000 lb.	1	340113100310	Maintenance grading of roadway, 4 passes, 3.0 MPH	\$631.65	Mile	B11L
			015433201910	Rent Grader, Self Propelled, 30,000 lb.	\$12,705.00	Month	None (Rental)
	Drill Rig	1	015433401865	Rent drill, rotary, crawler, 250hp	\$ 23,249.00	Month	None (Rental)
			023213100600	Subsurface investigation, boring and exploratory drilling, auger holes in earth	\$ 26.28	LF	B55
	Excavator 3.5 CY ~ 80K-100K lb.	1	312316420305	3.5 CY Excavator Capacity = 300 CY/hour	\$1.78	BCY	B12D
	Rip Rap Class II 18"-24"	2346		Assume \$5/mile Class II within 115 miles =	\$45.00	Ton	
	Rip Rap Class III 24"+			Assume \$6/mile Class III within 115 miles =	\$75.00	Ton	
4	M1 Haul Road Closure						
	Excavator 3.5 CY ~ 80K-100K lb.	1	312316420305	3.5 CY Excavator Capacity = 300 CY/hour	\$1.78	BCY	B12D
	Loader 5CY+	1	312323154080	Common Earth - 5 CY bucket, front-end loader	\$16.30	BCY	B10U
			015433204760	Rent front-end loader, articulating, 5.25-5.75 CY 270 hp	\$8,478.75	Month	None (Rental)
	Dozer D6	1	312213200170	8,100-10,000 SF Grading, Dozer	\$1,378.08	each	B10L
			015433204260	Rent Dozer, crawler, torque converter, diesel 200 hp	\$15,960.00	Month	None (Rental)
	Grader 30,000 lb.	1	340113100310	Maintenance grading of roadway, 4 passes, 3.0 MPH	\$631.65	Mile	B11L
			015433201910	Rent Grader, Self Propelled, 30,000 lb.	\$12,705.00	Month	None (Rental)
	Off-Road Haul Truck	1	312323205110	22 CY, 5 MPH, 15 min wait/ld./unld, 2-mile cycle	\$6.32	LCY	B34F

**Table E-14. Brodie 1 Mine, Equipment Cost Details for Alternative 3,
Disposal in On-Navajo Nation Regional Repository**

Notes:

'	Foot
"	Inch
BCY	Bank cubic yard
CY	Cubic yard
hp	Horsepower
K	Thousand
lb.	Pound
LCY	Loose cubic yard
ld.	Loaded
LF	Linear foot
M2	Square meters
MPH	Mile per hour
psi	Pound per square inch
QTY	Quantity
SF	Square feet
unld.	Unloaded
W	Width

**Table E-15. Brodie 1 Mine, Regional Repository Cost Details for Alternative 3,
Disposal in On-Navajo Nation Regional Repository**

Site Measurements	QTY	Unit	QTY	Unit		
Repository Area	0.73	AC	31,829	SF		
Repository topsoil 3"	295	CY				
Borrow Topsoil 3" (1.5 AC)	605	CY				
Clean Fill Volume (Volume From Estimate calculator)	5,710	CY				
Soil Barrow Fill Volume (at 10' depth need 0.1 AC Area)	-2,317	CY				
Waste Volume	5,710	CY				
Laydown Area (google earth)	0.2	AC	8,712	SF		
Laydown topsoil 3"	81	CY				
Engineering Design	Equipment List	Crew	Unit	Amount	Price	Cost
Project Manager			Hour	2.51	\$ 158.00	\$ 396
Project Engineer			Hour	10.0	\$ 122.00	\$ 1,221
Design Engineer			Hour	5.0	\$ 158.00	\$ 791
CAD/GIS Operator			Hour	2.5	\$ 102.00	\$ 256
Admin			Hour	1.00	\$ 67.00	\$ 67
Reproduction			LS	3.0	\$ 500.00	\$ 1,500
						\$ 4,231
Site Prep	Equipment List	Crew	Daily	Unit	Days	Cost
Clearing and Grubbing	Mulching EQ	B-65	\$ 1,712.23	1	0.31	\$ 531
Storm Drain Channel Excavation(includes laydown+25%)	Excavator 3.5 CY = 300CY/hr.	B-12D	\$ 3,664.80	1	3.0	\$ 10,949
Storm Drain Channel Armoring (Riprap)(includes laydown and Pond +25%)	Rip Rap Class II 18"-24"		\$ 52.00	30		\$ 1,554
	Excavator 3.5 CY = 300CY/hr.	B-12D	\$ 3,664.80	1	0.6	\$ 2,190
	Loader 5.5CY	B-10U	\$ 2,032.94	1	0.6	\$ 1,215
						\$ 4,958
Water Berm Construction and Compaction (includes laydown +25%)	Excavator 3.5 CY = 300CY/hr.	B-12D	\$ 3,664.80	1		\$ -
	Vibrating plate, Gas 21"	B-18	\$ 1,796.16	1	3.0	\$ 5,366
	Water Truck	B-59	\$ 1,124.99	1	3.0	\$ 3,361
						\$ 8,727

**Table E-15. Brodie 1 Mine, Regional Repository Cost Details for Alternative 3,
Disposal in On-Navajo Nation Regional Repository**

Storm Drain Pond Excavation (includes laydown +25%)	Excavator 3.5 CY = 300CY/hr.	B-12D	\$ 3,664.80	1	1	\$ 3,344
						\$ 28,509
Excavation	Equipment List	Crew	Daily	Unit	Days	Cost
Topsoil Stripping and Stockpiling	Excavator 3.5 CY = 300CY/hr.	B-12D	\$ 3,664.80	1	1.0	\$ 3,593
	Off Road Haul Truck	B34F	\$ 1,653.82	3	1.0	\$ 4,864
	Loader 5.5CY	B-10U	\$ 2,032.94	1	1.0	\$ 1,993
	Water Truck	B-59	\$ 1,124.99	1	1.0	\$ 1,103
						\$ 11,553
Repository and Soil Barrow Excavation and Stockpiling	Excavator 3.5 CY = 300CY/hr.	B-12D	\$ 3,664.80	1	2.9	\$ 10,766
	Off Road Haul Truck 22CY	B34F	\$ 1,653.82	2	2.9	\$ 9,717
	Dozer 300 HP	B-10M	\$ 2,931.70	1	2.9	\$ 8,612
	Water Truck	B-59	\$ 1,124.99	1	2.9	\$ 3,305
						\$ 32,400
Borrow Material Screening	Loader 5.5CY	B-10U	\$ 2,032.94	1	2.9	\$ 5,972
	Screen Plant		\$ 4,725.00	1	2.9	\$ 13,880
	Water Truck	B-59	\$ 1,124.99	1	2.9	\$ 3,305
						\$ 23,157
Bottom Grading	30,000 lb. Grader	B-11L	\$ 2,413.50	1	2.9	\$ 7,090
						\$ 74,200
Operation	Equipment List	Crew	Daily	Unit	Days	Cost
Waste Screening	Loader 5.5CY	B-10U	\$ 2,032.94	1	4.9	\$ 10,050
	Screen Plant		\$ 4,725.00	1	4.9	\$ 23,359
	Off Road Haul Truck	B34F	\$ 1,653.82	3	4.9	\$ 24,528
	Dozer 300 HP	B-10M	\$ 2,931.70	1	4.9	\$ 14,494
	Water Truck	B-59	\$ 1,124.99	1	4.9	\$ 5,562
						\$ 77,993
Waste Grading of Each Lift + Waste Compaction of Each Lift	30,000 lb. Grader	B-32A	\$ 3,856.00	1	4.9	\$ 19,063
	Water Truck	B-59	\$ 1,124.99	1	4.9	\$ 5,562
						\$ 24,625
						\$ 102,617

**Table E-15. Brodie 1 Mine, Regional Repository Cost Details for Alternative 3,
Disposal in On-Navajo Nation Regional Repository**

Closure	Equipment List	Crew	Daily	Unit	Days	Cost
Waste Final Grading	30,000 lb. Grader	B-11L	\$ 2,413.50	1	0.24	\$ 588
	Water Truck	B-59	\$ 1,124.99	1	0.24	\$ 274
						\$ 862
Cap Cover Installation	Gravel Delivered - 1" Rock Crushed (Tons)		\$ 10.95	78	3.4	\$ 2,895
	Gravel Delivered - 5/8" Rock Crushed (Tons)		\$ 18.80	221	3.4	\$ 14,098
	Loader 5.5CY	B-10U	\$ 2,032.94	1	6.4	\$ 12,997
	Off Road Haul Truck	B34F	\$ 1,653.82	4	3.4	\$ 22,446
	Dozer 300 HP	B-10M	\$ 2,931.70	1	3.4	\$ 9,947
	30,000 lb. Grader	B-11L	\$ 2,413.50	1	3.4	\$ 8,189
	Water Truck	B-59	\$ 1,124.99	1	3.4	\$ 3,817
						\$ 74,389
						\$ 75,251
Reclamation	Equipment List	Crew	Unit	Amount	Price	Cost
Revegetation Mat			SF	2,614	\$ 1.68	\$ 4,392
Hay Bales/Wattles and Silt Fence			LF	985	\$ 8.55	\$ 8,422
Fertilizer, Seed, and Mulch			SY	2614	\$ 4.02	\$ 10,508
						\$ 23,322
Other Line Items	Equipment List	Crew	Unit	Amount	Price	Cost
Fence			LF	316	\$ 38.00	\$ 12,008
Survey			AC	0.73	\$ 3,425.00	\$ 2,503
Water Well, Pump, Tank and Generator			LS	1	\$ 98,200.00	\$ 98,200
Well Installation			LS	1	\$ 120,000.00	\$ 120,000
						\$ 232,711
Subtotal Construction Costs (Not Including Design)						\$ 536,610
Contractor Site Overhead						\$ 221,615
Travel + Lodging:						\$ 48,110
Mobilization / Demobilization:						\$ 73,675
Level of Accuracy (20%)						\$ 107,322
Navajo Tax (6%):						\$ 56,353
Total Construction Cost:						\$ 1,047,916
Yearly Post Removal Site Control (PRSC) Costs						

**Table E-15. Brodie 1 Mine, Regional Repository Cost Details for Alternative 3,
Disposal in On-Navajo Nation Regional Repository**

Site Inspections			1	EA	\$1,000.00	\$ 1,000
Site Maintenance			1% of Construction Cost			\$ 10,479
Subtotal PRSC Costs						\$ 11,479
PRSC Contingencies			15%			\$ 1,722
Navajo Tax			6% of PRSC and Contingencies Cost			\$ 792
Total Yearly PRSC Cost						\$ 13,993
Present Value of PRSC Costs Based on 1,000 Year Life at 3.50%			PV Factor = 28.571			\$ 399,797
Total Present Worth						\$ 1,447,713
Cost Per CY:						\$ 254

Notes:

"	Inch
AC	Acres
CAD	Computer-aided design
CY	Cubic yard
EA	Each
EQ	Equipment
GIS	Geographic information system
hr	Hour
lb.	Pound
LF	Linear feet
LS	Lump sum
N/A	Not applicable
PV	Present value
PRSC	Post-removal site control
SY	Square yard

**Table E-16. Brodie 1 Mine, Cost Estimate Details for Alternative 3,
Disposal in On-Navajo Nation Regional Repository**

Engineering Design	Crew	Unit	Amount	Price	Cost
Project Manager	N/A	Hour	293	\$ 158.00	\$ 46,294
Project Engineer	N/A	Hour	1170	\$ 122.00	\$ 142,740
Design Engineer	N/A	Hour	585	\$ 158.00	\$ 92,430
CAD/GIS Operator	N/A	Hour	293	\$ 102.00	\$ 29,886
Admin	N/A	Hour	117	\$ 67.00	\$ 7,839
Reproduction	N/A	LS	3	\$ 500.00	\$ 1,500
					\$ 320,689
Planning Documents	Crew	Unit	Amount	Price	Cost
Project Manager	N/A	Hour	405	\$ 158.00	\$ 63,990
Project Engineer	N/A	Hour	1620	\$ 122.00	\$ 197,640
CAD/GIS Operator	N/A	Hour	405	\$ 102.00	\$ 41,310
Admin	N/A	Hour	162	\$ 67.00	\$ 10,854
Reproduction	N/A	LS	3	\$ 500.00	\$ 1,500
					\$ 315,294
Resource Surveys	Crew	Unit	Amount	Price	Cost
Cultural Resources Mitigation	N/A	Each	1	\$ 2,366.64	\$ 2,367
Biological Resources Mitigation	N/A	Each	1	\$ 4,733.28	\$ 4,733
Geotechnical Testing and Report	N/A	Each	1	\$ 4,733.28	\$ 4,733
Pre-Project Aerial LIDAR Survey	N/A	Each	0	\$ 30,000.00	\$ -
Post-Project Aerial LiDAR Survey	N/A	Each	1	\$ 7,099.92	\$ 7,100
					\$ 18,933
Confirmation Sampling	Crew	Unit	Amount	Price	Cost
Developing Sampling and Analysis Plan					
Project Geologist	N/A	Hour	360	\$ 158.00	\$ 56,880
Project Manager	N/A	Hour	180	\$ 111.00	\$ 19,980
CAD/GIS Operator	N/A	Hour	180	\$ 122.00	\$ 21,960
Project Chemist	N/A	Hour	360	\$ 111.00	\$ 39,960
Health and Safety Manager	N/A	Hour	180	\$ 151.00	\$ 27,180
Admin	N/A	Hour	72	\$ 67.00	\$ 4,824
Reproduction	N/A	LS	3	\$ 250.00	\$ 750
Sampling					
Sampling Team - Staff Geologist	N/A	Hour	7	\$ 77.00	\$ 547
Sampling Team - Staff Engineer	N/A	Hour	7	\$ 81.00	\$ 575
Travel	N/A	Day	2	\$ 170.00	\$ 340
Per Diem (96/55)	N/A	Day	2	\$ 151.00	\$ 302
Miscellaneous Field Supplies and Expenses	N/A	LS	1	\$ 1,209.83	\$ 1,210
Lab Analysis	N/A	LS	1	\$ 389.79	\$ 390
XRF Surveying					
Sampling Team - Staff Geologist	N/A	Hour	27	\$ 77.00	\$ 2,041
Sampling Team - Staff Engineer	N/A	Hour	27	\$ 81.00	\$ 2,147
Travel	N/A	Day	3	\$ 170.00	\$ 510
Per Diem (96/55)	N/A	Day	4	\$ 151.00	\$ 643
Miscellaneous Field Supplies and Expenses	N/A	LS	1	\$ 1,209.83	\$ 1,210
Lab Analysis	N/A	LS	1	\$ 389.79	\$ 390
Frisking Equipment	N/A	Month	2	\$ 144.00	\$ 341
					\$ 182,179

**Table E-16. Brodie 1 Mine, Cost Estimate Details for Alternative 3,
Disposal in On-Navajo Nation Regional Repository**

Reporting	Crew	Unit	Amount	Price	Cost
Project Geologist	N/A	Hour	316	\$ 105.00	\$ 33,180
Project Manager	N/A	Hour	158	\$ 175.00	\$ 27,650
Project Engineer	N/A	Hour	474	\$ 122.00	\$ 57,828
Chemist	N/A	Hour	158	\$ 111.00	\$ 17,538
CAD/GIS Operator	N/A	Hour	158	\$ 102.00	\$ 16,116
Admin	N/A	Hour	63	\$ 67.00	\$ 4,221
Reproduction	N/A	LS	3	\$ 500.00	\$ 1,500
					\$ 158,033
Mobilization/Demobilization	Crew	Unit	Amount	Price	Cost
Crew Mileage	N/A	Mile	5,040	\$ 0.56	\$ 2,822
Per Diem	N/A	Day	15	\$ 182.00	\$ 2,730
Labor	N/A	Day	15	\$ 300.00	\$ 4,500
Standard Equipment Mileage	N/A	Mile	5,040	\$ 0.56	\$ 2,822
Standard Equipment Rental	N/A	Day	2	\$ 17,657.42	\$ 35,315
					\$ 48,190
Haul Road Building	Crew	Daily	Unit #	Days	Cost
Excavator 3.5 cy ~ 80K-100K lb.	B12D	\$ 3,664.00	1	4	\$ 14,656
Dozer D6	B10M	\$ 2,931.70	1	6	\$ 17,590
Grader 30,000 lb.	B11L	\$ 2,413.50	1	4	\$ 9,654
Water Truck	B45	\$ 889.00	1	4	\$ 3,556
Off Road Haul Truck	B34F	\$ 1,653.82	4	4	\$ 26,461
Rip Rap Class II 18"-24"	NA	\$ 45.00	419.5	1	\$ 18,878
				Total	\$ 90,795
Excavation & Hauling	Crew	Daily	Unit #	Days	Cost
Loader 5cy+	B10U	\$ 2,032.94	1	5	\$ 10,165
Off Road Haul Truck	B34F	\$ 1,653.82	2	5	\$ 16,538
Grader 30,000 lb.	B11L	\$ 2,413.50	1	5	\$ 12,068
Excavator 3.5 cy ~ 80K-100K lb.	B12D	\$ 3,664.00	1	5	\$ 18,320
				Total	\$ 57,090
Reclamation	Crew	Daily	Unit #	Days	Cost
Off Road Haul Truck	B34F	\$ 1,653.82	1	6	\$ 9,923
Loader 5cy+	B10U	\$ 2,032.94	1	1	\$ 2,033
Grader 30,000 lb.	B11L	\$ 2,413.50	1	2	\$ 4,827
Excavator 3.5 cy ~ 80K-100K lb.	B12D	\$ 3,664.00	1	1	\$ 3,664
Dozer D6	B10M	\$ 2,931.70	1	1	\$ 2,932
Rip Rap Class II 18"-24"	NA	\$ 45.00	2346.3	1	\$ 105,584
Mine Area Reclamation Materials	N/A	\$ 68,239.50	1	1	\$ 12,686
				Total	\$ 141,648
Haul Road Reclamation	Crew	Daily	Unit #	Days	Cost
Excavator 3.5 cy ~ 80K-100K lb.	B12D	\$ 3,664.00	1	7	\$ 25,648
Loader 5cy+	B10U	\$ 2,032.94	1	7	\$ 14,231
Dozer D6	B10M	\$ 2,931.70	1	7	\$ 20,522
Grader 30,000 lb.	B11L	\$ 2,413.50	1	7	\$ 16,895
Off Road Haul Truck	B34F	\$ 1,653.82	2	7	\$ 23,153
Haul Road Reclamation Materials	N/A	\$ 21,225.60	1	1	\$ 21,226
				Total	\$ 122,930

**Table E-16. Brodie 1 Mine, Cost Estimate Details for Alternative 3,
Disposal in On-Navajo Nation Regional Repository**

Contractor Site Overhead	Crew	Unit	Amount	Price	Cost
Project Manager (10% of time)	N/A	Hour	9	\$ 175.00	\$ 1,504
Site Superintendent	N/A	Hour	86	\$ 191.00	\$ 16,418
H&S Officer	N/A	Hour	86	\$ 85.00	\$ 7,307
QA/QC Officer	N/A	Hour	86	\$ 85.00	\$ 7,307
Field Clerk	N/A	Hour	86	\$ 19.00	\$ 1,633
Fuel for Site Vehicles	N/A	Month	2	\$ 1,600.00	\$ 3,897
Port-o-let Rental (4)	N/A	Month	2	\$ 208.00	\$ 358
Permanent Fencing Installation and Demolition	N/A	LF	567	\$ 41.92	\$ 23,787
Job Trailers (1)	N/A	Month	0	\$ 269.00	\$ 116
Storage Boxes (1)	N/A	Month	0	\$ 94.50	\$ 41
Field Office Lights/HVAC (1)	N/A	Month	0	\$ 179.00	\$ 77
Generator (1)	N/A	Month	1	\$ 2,400.00	\$ 2,063
Fuel for Generator	N/A	Gallons	258	\$ 4.00	\$ 1,032
Telephone/internet (1)	N/A	Month	0	\$ 384.00	\$ 165
Field Office Equipment	N/A	Month	0	\$ 230.00	\$ 99
Field Office Supplies	N/A	Month	0	\$ 96.00	\$ 41
Trash (1 dumpster)	N/A	Month	0	\$ 910.00	\$ 391
Clin 1034 High Volume Air Sampling (4)	N/A	Month	2	\$ 383.00	\$ 658
Clin 1025 Ludlum 2121 and 43-10-1	N/A	Month	0	\$ 275.00	\$ 118
Air Monitoring Lab Confirmation Sampling (5 samples per day)	N/A	Day	43	\$ 600.00	\$ 25,788
Clin 1036 Personal Air Monitor	N/A	Month	6	\$ 204.00	\$ 1,224
Clin 1038 Personal Dust Monitor	N/A	Month	6	\$ 1,555.00	\$ 9,330
Clin 1068 Personal Dosimeter Badge	N/A	Month	6	\$ 59.00	\$ 354
Truck Scales	N/A	Month	0	\$ 300.00	\$ 129
Construction Water (excavation)	N/A	Gallon	3100	\$ 0.05	\$ 155
Construction Water (hauling waste soil plus cap mat'l)	N/A	Gallon	63000	\$ 0.05	\$ 3,150
6,000 Gallon Water Truck and Operator (1)	N/A	Day	9	\$ 889.00	\$ 7,642
Portal Water Tower Trailer, 10,000 gallons (1)	N/A	Day	9	\$ 172.36	\$ 1,482
					\$ 116,264
Third-Party Oversight	Crew	Unit	Amount	Price	Cost
Travel and Lodging (4 people)	N/A	Day	34	\$ 151.00	\$ 5,192
Labor	N/A	Hour	344	\$ 80.00	\$ 27,507
Car Rental (4 cars)	N/A	Month	2	\$ 400.00	\$ 688
Car Fuel	N/A	Month	2	\$ 760.00	\$ 1,307
					\$ 34,693
Level of Accuracy (20%)	Crew	Unit	Amount	Price	Cost
20% of Construction Cost	N/A	N/A	N/A	N/A	\$ 82,242
Navajo Tax (6%)	Crew	Unit	Amount	Price	Cost
6% of Confirmation Sampling, Construction, Contractor Overhead, Mobilization / Demobilization, and Third Party Oversight Costs	N/A	N/A	N/A	N/A	\$ 52,487
			GRAND TOTAL		\$ 1,790,589

**Table E-16. Brodie 1 Mine, Cost Estimate Details for Alternative 3,
Disposal in On-Navajo Nation Regional Repository**

PRSC Costs	Crew	Unit	Amount	Price	Cost
Bi-annual Inspection (4 person crew, 1 day, 10 hr/day)	N/A	Hour	80	\$ 85.00	\$ 6,800
Mileage (Farmington, NM, to Site, roundtrip)	N/A	Mile	217	\$ 0.58	\$ 126
Inspection Crew Per Diem	N/A	Day	8	\$ 151.00	\$ 1,208
Assumed Annual Maintenance costs (revegetation, grading, watering)	N/A	SY	2,236	\$ 1.11	\$ 2,484
Preperation of Semi-annual Reports (Professional Engineer)	N/A	Hour	80	\$ 120.00	\$ 9,600
PRSC Annual Cost					\$ 20,218
PRSC Contingency (15%)					\$ 3,033
Navajo Tax (6% of PRSC and Contingencies Cost					\$ 1,395
Total PRSC Annual Cost					\$ 24,646
Road PRSC Costs (every 10 years)	Crew	Unit	Amount	Price	Cost
Mileage (Farmington, NM, to Site, roundtrip, 3 vehicles, 3 trips every 10 years)	N/A	Mile	224	\$ 0.06	\$ 13
Construction Crew Per Diem and Labor (9 people, 3 trips every 10 years, 2 extra days to mob/demob)	N/A	Day	2	\$ 433.80	\$ 895
Widen, Grade, Compact Equipment Rental Grader, Loader, Excavator, Dozer, Haul Truck	N/A	Day	2	\$ 1,221.76	\$ 2,521
Gravel (assumed 5% of total area, 750 tons per acre)	N/A	Ton	63.20	\$ 1.80	\$ 114
Riprap Class II (assume 3 tons per 1,000 LF of road)	N/A	Ton	13.77	\$ 5.50	\$ 76
PRSC Annual Cost					\$ 3,619
PRSC Contingency (15%)					\$ 543
Navajo Tax (6% of PRSC and Contingencies Cost					\$ 250
Total PRSC Annual Cost					\$ 4,412

Notes:

"

CAD

CY

GIS

H&S

hp

hr

HVAC

K

lb.

LF

LiDAR

LS

M2

N/A

NM

PRSC

QA/QC

SY

XRF

Inch

Computer-aided design

Cubic yard

Geographic information system

Health and safety

Horsepower

Hour

Heating, ventilation, and air conditioning

Thousand

Pound

Linear feet

Light detection and ranging

Lump sum

Square meters

Not applicable

New Mexico

Post-removal site control

Quality assurance/quality control

Square yard

X-ray fluorescence

**Table E-17. Brodie 1 Mine, Cost Estimate Summary for Alternative 3,
Disposal in On-Navajo Nation Regional Repository**

Waste Volume	1310 CY
Removal Area	0.22 AC
Haul Road Building	Ratio T&M Cost
Excavator 3.5 cy ~ 80K-100K lb.	\$ 14,656
Dozer D6	\$ 17,590
Grader 30,000 lb.	\$ 9,654
Water Truck	\$ 3,556
Off Road Haul Truck	\$ 26,461
Rip Rap Class II 18"-24"	\$ 18,878
Subtotals Step 1	\$ 90,795
Excavation & Hauling	Unit Cost
Heavy Lift Helicopter	\$ -
Support Helicopter	\$ -
Loader 5cy+	\$ 10,165
Off Road Haul Truck	\$ 16,538
Grader 30,000 lb.	\$ 12,068
Excavator 3.5 cy ~ 80K-100K lb.	\$ 18,320
Subtotals Step 2	\$ 57,090
Reclamation	Unit Cost
Off Road Haul Truck	\$ 9,923
Loader 5cy+	\$ 2,033
Grader 30,000 lb.	\$ 4,827
Excavator 3.5 cy ~ 80K-100K lb.	\$ 3,664
Dozer D6	\$ 2,932
Rip Rap Class II 18"-24"	\$ 105,584
Mine Area Reclamation Materials	\$ 12,686
Subtotals Step 3	\$ 141,648
Haul Road Reclamation	Unit Cost
Excavator 3.5 cy ~ 80K-100K lb.	\$ 25,648
Loader 5cy+	\$ 14,231
Dozer D6	\$ 20,522
Grader 30,000 lb.	\$ 16,895
Off Road Haul Truck	\$ 23,153
Haul Road Reclamation Materials	\$ 21,226
Subtotals Step 4	\$ 121,674
Subtotal Construction	\$ 411,208
Other Costs	Unit Cost
Non-Construction Costs	
Engineering Design	\$ 320,689
Planning Documents	\$ 315,294
Resource Surveys	\$ 18,933
Confirmation Sampling	\$ 182,179
Reporting	\$ 158,033
Contractor Site Overhead	\$ 116,264
Mobilization / Demobilization	\$ 48,190
Travel+ Lodging (Construction Workers)	\$ 50,378
Level of Accuracy (20%)	\$ 82,242

**Table E-17. Brodie 1 Mine, Cost Estimate Summary for Alternative 3,
Disposal in On-Navajo Nation Regional Repository**

Third-Party Oversight	\$	34,693
Navajo Tax (6%)	\$	52,487
Subtotals Step 6	\$	1,379,381
Total Capital Costs	\$	1,790,589
Yearly On-Site PRSC Costs	Unit Cost	
Bi-annual Inspection (4 person crew, 3 days, 10 hr/day)	\$	6,800
Mileage (Farmington, NM, to Site, roundtrip)	\$	126
Inspection Crew Per Diem	\$	1,208
Assumed Annual Maintenance costs (revegetation, grading, watering)	\$	2,484
Preperation of Semi-annual Reports (Professional Engineer)	\$	9,600
Subtotal PRSC Costs	\$	20,218
PRSC Contingencies (15%)	\$	3,033
Navajo Tax (6% of PRSC and Contingencies Cost)	\$	1,395
Total Yearly PRSC Costs	\$	24,646
Present Value of PRSC Costs Based on 10-Year Life at 3.50% (PV Factor = 8.317)	\$	204,983
Road PRSC Costs (Every 10 Years)	Unit Cost	
Mileage (Farmington, NM, to Site, roundtrip)	\$	57
Construction Crew Per Diem and Labor (9 people)	\$	2,603
Widen, Grade, Compact Equipment Rental (Grader, Loader, Excavator, Dozer, Haul Truck)	\$	7,331
Gravel (assumed 5% of total area, 750 tons per acre)	\$	474
Riprap Class II (assume 3 tons per 1,000 LF of road)	\$	315
Subtotal PRSC Costs	\$	10,779
PRSC Contingencies (15%)	\$	1,617
Navajo Tax (6% of PRSC and Contingencies Cost)	\$	744
Total Yearly PRSC Costs	\$	13,140
Present Value of PRSC Costs Based on 1,000-Year Life at 3.50% (PV Factor = 28.571)	\$	375,423
Regional ET Cap Cost Share with Block K (23%)		
Regional Repository Construction Cost	\$	240,287
Regional Repository Total Yearly PRSC Costs	\$	3,209
Regional ET Cap Cost per CY (Construction and 1000-Year PRSC Cost)	\$	254
Regional ET Cap Shared Cost	\$	332,137
Grans Total Capital Costs	\$	2,030,876
TOTAL COSTS	\$	2,703,132

Notes:

"

AC

CY

ET

hp

hr

K

lb.

LF

NM

PRSC

PV

T&M

Inch

Acres

Cubic yard

Evapotranspiration

Horsepower

Hour

Thousand

Pound

Linear feet

New Mexico

Post-removal site control

Present value

Time and material

**Table E-18. Brodie 1 Mine, Cost Estimate Scenario Assumptions for Alternative 4,
Off-Navajo Nation Disposal at White Mesa Mill**

Technology	Assumptions	Cost Effects
Excavation Methods	Waste removed by an excavator is assumed to be removed with a large excavator, unless specified	Excavators can operate on steeper terrain than bulldozers and are better at moving waste uphill. Bulldozers cost less to operate. Spider excavators or other specialized equipment are more expensive.
	Any disturbed surface can be restored using grading and erosion controls	Quantities of erosion control materials and grading may be lower than costed
	Land is barren to warrant no clearing or grubbing	Costs of clearing and grubbing are zero
	All waste specified in the risk assessment will be excavated	Volumes of excavated waste may be lower than costed
	The site is accessible to haul trucks and trucks can be easily loaded	Accessing difficult-to-reach mines increase costs.
Soil and Waste Sorting	Mine waste will be sorted based on grain size; rock greater than 3 inches will be segregated	NA
Operating Mill	Waste will be transported 63 miles in highway-legal trucks from the mine site to the White Mesa mill	Greater distance to repository increases costs
	Waste weighs 1.6 tons per cubic yard	Denser waste will increase costs
	Tipping fee at uranium mill to cover milling costs	Higher tipping fee results in increased costs; current tipping fees are from previous cost estimate
	0.01 percent by weight recoverable uranium in waste, equal to 0.12 pounds	Higher percent of recoverable uranium increases economic value of waste, thus decreasing net costs
	Cycle time limited to 25 trucks per day, due to space. Assumes maximum number of trucks (25) for fastest production rate.	Less trucks will reduce production time and require more time on-site, increasing costs.
	Uranium market price is \$30/pound	Market value at time of milling will increase or decrease economic value of waste, thus increasing or decreasing costs
	PRSC inspection of the mine site will be completed for 10 years	More PRSC inspections will increase costs
	The waste excavation area will not require cover soil or amendment	If cover soil or amendments are required, costs will increase

Notes:

CY	Cubic yard
ET	Evapotranspiration
NA	Not applicable - inherent assumption
PRSC	Post-removal site control

**Table E-19. Brodie 1 Mine, Crew Time Productivity Calculations for Alternative 4,
Off-Navajo Nation Disposal at White Mesa Mill**

	Waste Volume	1,310	CY		
	Removal Area	0.22	AC		
Step	Brodie 1 Haul Road Installation				
1	Action	QTY	Unit	Production CY	Days
	Brodie 1 Lower Haul Road - Excavation	2,875	LCY	1,531	1.9
	Brodie 1 Upper Access Road - Excavation	1,760	LCY	1,531	1.15
	Rock Fields	155	CY	2,652	0.06
				Control Days	3
Step	Brodie 1 Excavation				
2	Action	QTY	Unit	Production CY	Days
	Waste Removal WP M1 and Excavate Drainage - Excavator	1,638	LCY	419	3.9
		1,638		Control Days	3.9
Step	Brodie 1 Restoration				
3	Action	QTY	Unit	Production Rate	Days
	Clean Borrow Fill	807	CY	5,304	0.2
	Grading	2,236	SY	1.3 Days for 2,222 SY	1.3
	Fertilizer, Seed, Mulch	2,236	SY	1,000	2.2
	Erosion Control - Erosion Control Blanket	980	SY	1,000	1.0
	Erosion Control - Coir Logs/Wattles	240	LF	1,000	0.2
	Gabion Weir	0	SY	60	0.0
	Rock Berms	219	LCY	3,864	0.5
	Rock Fields	650	CY	5,304	0.12
				Control Days	6
Step	Brodie 1 Haul Road Restoration				
4	Action	QTY	Unit	Production Rate	Days
	Fertilizer, Seed, Mulch	5,280	SY	1,000	5
	Haul Road Reclamation - Haul Fill	4,635	LCY	5,304	0.9
				Control Days	6
				TOTAL PROJECT DAYS	19
				Slowest Rate Project Days:	19

Notes:

AC

BCY Bank cubic yard

CY Cubic yard

LCY Loose cubic yard

LF Linear foot

Mi Mile

QTY Quantity

SY Square yard

**Table E-20. Brodie 1 Mine, Equipment Cost Details for Alternative 4,
Off-Navajo Nation Disposal at White Mesa Mill**

Step	Equipment List	QTY	RSMeans #	RSMeans Description	Unit Cost	Unit	Crew
1	M1 Haul Road Building						
	Excavator 3.5 CY ~ 80K-100K lb.	1	312316420305	3.5 CY Excavator Capacity = 300 CY/hour	\$ 1.78	BCY	B12D
	Dozer D6	1	312213200170	8,100-10,000 SF Grading, Dozer	\$ 1,378.08	each	B10L
			015433204260	Rent Dozer, crawler, torque converter, diesel 200 hp	\$ 15,960	Month	None (Rental)
	Grader 30,000 lb.	1	340113100310	Maintenance grading of roadway, 4 passes, 3.0 MPH	\$ 631.65	Mile	B11L
			015433201910	Rent Grader, Self Propelled, 30,000 lb.	\$ 12,705	Month	None (Rental)
	Off-Road Haul Truck	4	312323205110	22 CY, 5 MPH, 15 min wait/lb./unlb, 2-mile cycle	\$ 6.32	LCY	B34F
2	M1 Excavation						
	Off-Road Haul Truck	2	312323205110	22 CY, 5 MPH, 15 min wait/lb./unlb, 2-mile cycle	\$ 6.32	LCY	B34F
	Loader 5cy+	1	312323154080	Common Earth - 5cy bucket, front end loader	\$ 16.30	BCY	B10U
			015433204760	Rent front end loader, articulating, 5.25-5.75 CY 270 HP	\$ 8,478.75	Month	None (Rental)
	Grader 30,000 lb.	1	340113100310	Maintenance grading of roadway, 4 passes, 3.0 MPH	\$ 631.65	Mile	B11L
			015433201910	Rent Grader, Self Propelled, 30,000 lb.	\$ 12,705	Month	None (Rental)
	Excavator 3.5 CY ~ 80K-100K lb.	1	312316420305	3.5 CY Excavator Capacity=300 CY/hour	\$ 1.78	BCY	B12D
3	M1 Reclamation						
	Off-Road Haul Truck	1	312323205110	22 CY, 5 MPH, 15 min wait/lb./unlb, 2-mile cycle	\$ 6.32	LCY	B34F
	Loader 5CY+	1	312323154080	Common Earth - 5 CY bucket, front-end loader	\$ 16.30	BCY	B10U
			015433204760	Rent front-end loader, articulating, 5.25-5.75 CY 270 hp	\$ 8,478.75	Month	None (Rental)
	Dozer D6	1	312213200170	8,100-10,000 SF Grading, Dozer	\$ 1,378.08	each	B10L
			015433204260	Rent Dozer, crawler, torque converter, diesel 200 hp	\$ 15,960	Month	None (Rental)

**Table E-20. Brodie 1 Mine, Equipment Cost Details for Alternative 4,
Off-Navajo Nation Disposal at White Mesa Mill**

	Grader 30,000 lb.	1	340113100310	Maintenance grading of roadway, 4 passes, 3.0 MPH	\$ 631.65	Mile	B11L
			015433201910	Rent Grader, Self Propelled, 30,000 lb.	\$ 12,705	Month	None (Rental)
	Excavator 3.5 CY ~ 80K-100K lb.	1	312316420305	3.5 CY Excavator Capacity = 300 CY/hour	\$ 1.78	BCY	B12D
	Rip Rap Class II 18"-24"	2346		Assume \$5/mile Class II within 115 miles =	\$ 45.00	Ton	
4	M1 Haul Road Closure						
	Excavator 3.5 CY ~ 80K-100K lb.	1	312316420305	3.5 CY Excavator Capacity = 300 CY/hour	\$ 1.78	BCY	B12D
	Loader 5CY+	1	312323154080	Common Earth - 5 CY bucket, front-end loader	\$ 16.30	BCY	B10U
			015433204760	Rent front-end loader, articulating, 5.25-5.75 CY 270 hp	\$ 8,478.75	Month	None (Rental)
	Dozer D6	1	312213200170	8,100-10,000 SF Grading, Dozer	\$ 1,378.08	each	B10L
			015433204260	Rent Dozer, crawler, torque converter, diesel 200 hp	\$ 15,960	Month	None (Rental)
	Grader 30,000 lb.	1	340113100310	Maintenance grading of roadway, 4 passes, 3.0 MPH	\$ 631.65	Mile	B11L
			015433201910	Rent Grader, Self Propelled, 30,000 lb.	\$ 12,705	Month	None (Rental)
	Off-Road Haul Truck	1	312323205110	22 CY, 5 MPH, 15 min wait/ld./unld, 2-mile cycle	\$ 6.32	LCY	B34F

Notes:

' Foot
 " Inch
 BCY Bank cubic yard
 CY Cubic yard
 hp Horse power
 K Thousand
 lb. Pound
 LCY Loose cubic yard
 ld. Loaded
 LF Linear foot
 M2 Square meters
 MPH Mile per hour
 psi Pound per square inch
 QTY Quantity
 SF Square feet
 unld. Unloaded
 W Width

**Table E-21. Brodie 1 Mine, Cost Estimate Details for Alternative 4,
Off-Navajo Nation Disposal at White Mesa Mill**

Engineering Design	Crew	Unit	Amount	Price	Cost
Project Manager	N/A	Hour	293	\$ 158	\$ 46,294
Project Engineer	N/A	Hour	1,170	\$ 122	\$ 142,740
Design Engineer	N/A	Hour	585	\$ 158	\$ 92,430
CAD/GIS Operator	N/A	Hour	293	\$ 102	\$ 29,886
Admin	N/A	Hour	117	\$ 67	\$ 7,839
Reproduction	N/A	LS	3	\$ 500	\$ 1,500
					\$ 320,689
Planning Documents	Crew	Unit	Amount	Price	Cost
Project Manager	N/A	Hour	405	\$ 158	\$ 63,990
Project Engineer	N/A	Hour	1,620	\$ 122	\$ 197,640
CAD/GIS Operator	N/A	Hour	405	\$ 102	\$ 41,310
Admin	N/A	Hour	162	\$ 67	\$ 10,854
Reproduction	N/A	LS	3	\$ 500	\$ 1,500
					\$ 315,294
Resource Surveys	Crew	Unit	Amount	Price	Cost
Cultural Resources Mitigation	N/A	Each	1	\$ 2,366.64	\$ 2,367
Biological Resources Mitigation	N/A	Each	1	\$ 4,733.28	\$ 4,733
Geotechnical Testing and Report	N/A	Each	1	\$ 4,733.28	\$ 4,733
Pre-Project Aerial LIDAR Survey	N/A	Each	0	\$ 30,000.00	\$ -
Post-Project Aerial LiDAR Survey	N/A	Each	1	\$ 7,099.92	\$ 7,100
					\$ 18,933
Confirmation Sampling	Crew	Unit	Amount	Price	Cost
Developing Sampling and Analysis Plan					
Project Geologist	N/A	Hour	360	\$ 158	\$ 56,880
Project Manager	N/A	Hour	180	\$ 111	\$ 19,980
CAD/GIS Operator	N/A	Hour	180	\$ 122	\$ 21,960
Project Chemist	N/A	Hour	360	\$ 111	\$ 39,960
Health and Safety Manager	N/A	Hour	180	\$ 151	\$ 27,180
Admin	N/A	Hour	72	\$ 67	\$ 4,824
Reproduction	N/A	LS	3	\$ 250	\$ 750
Sampling					
Sampling Team - Staff Geologist	N/A	Hour	7	\$ 77	\$ 547
Sampling Team - Staff Engineer	N/A	Hour	7	\$ 81	\$ 575
Travel	N/A	Day	2	\$ 170	\$ 340
Per Diem (96/55)	N/A	Day	2	\$ 151	\$ 302
Miscellaneous Field Supplies and Expenses	N/A	LS	1	\$ 1,209.83	\$ 1,210
Lab Analysis	N/A	LS	1	\$ 389.79	\$ 390
XRF Surveying					
Sampling Team - Staff Geologist	N/A	Hour	27	\$ 77	\$ 2,041
Sampling Team - Staff Engineer	N/A	Hour	27	\$ 81	\$ 2,147
Travel	N/A	Day	3	\$ 170	\$ 510
Per Diem (96/55)	N/A	Day	4	\$ 151	\$ 643
Miscellaneous Field Supplies and Expenses	N/A	LS	1	\$ 1,209.83	\$ 1,210
Lab Analysis	N/A	LS	1	\$ 389.79	\$ 390
Frisking Equipment	N/A	Month	2	\$ 144	\$ 341
					\$ 182,179

**Table E-21. Brodie 1 Mine, Cost Estimate Details for Alternative 4,
Off-Navajo Nation Disposal at White Mesa Mill**

Reporting	Crew	Unit	Amount	Price	Cost
Project Geologist	N/A	Hour	316	\$ 105	\$ 33,180
Project Manager	N/A	Hour	158	\$ 175	\$ 27,650
Project Engineer	N/A	Hour	474	\$ 122	\$ 57,828
Chemist	N/A	Hour	158	\$ 111	\$ 17,538
CAD/GIS Operator	N/A	Hour	158	\$ 102	\$ 16,116
Admin	N/A	Hour	63	\$ 67	\$ 4,221
Reproduction	N/A	LS	3	\$ 500	\$ 1,500
					\$ 158,033
Mobilization/Demobilization	Crew	Unit	Amount	Price	Cost
Crew Mileage	N/A	Mile	5,040	\$ 0.56	\$ 2,822
Per Diem	N/A	Day	15	\$ 182	\$ 2,730
Labor	N/A	Day	15	\$ 300	\$ 4,500
Standard Equipment Mileage	N/A	Mile	5,040	\$ 0.56	\$ 2,822
Standard Equipment Rental	N/A	Day	2	\$ 17,657.42	\$ 35,315
					\$ 48,190
Haul Road Building	Crew	Daily	Unit #	Days	Cost
Excavator 3.5 cy ~ 80K-100K lb.	B12D	\$ 3,664.00	1	4	\$ 14,656
Dozer D6	B10M	\$ 2,931.70	1	4	\$ 11,727
Grader 30,000 lb.	B11L	\$ 2,413.50	1	4	\$ 9,654
Water Truck	B45	\$ 889.00	1	4	\$ 3,556
Off Road Haul Truck	B34F	\$ 1,653.82	4	4	\$ 26,461
Rip Rap Class II 18"-24"	NA	\$ 45.00	419.5	1	\$ 18,878
				Total	\$ 84,931
Excavation & Hauling	Crew	Daily	Unit #	Days	Cost
Loader 5cy+	B10U	\$ 2,032.94	1	4	\$ 8,132
Off Road Haul Truck	B34F	\$ 1,653.82	0	4	\$ -
Grader 30,000 lb.	B11L	\$ 2,413.50	1	4	\$ 9,654
Excavator 3.5 cy ~ 80K-100K lb.	B12D	\$ 3,664.00	1	4	\$ 14,656
				Total	\$ 32,442
Reclamation	Crew	Daily	Unit #	Days	Cost
Off Road Haul Truck	B34F	\$ 1,653.82	1	6	\$ 9,923
Loader 5cy+	B10U	\$ 2,032.94	1	1	\$ 2,033
Grader 30,000 lb.	B11L	\$ 2,413.50	1	2	\$ 4,827
Excavator 3.5 cy ~ 80K-100K lb.	B12D	\$ 3,664.00	1	1	\$ 3,664
Dozer D6	B10M	\$ 2,931.70	1	1	\$ 2,932
Rip Rap Class II 18"-24"	NA	\$ 45.00	2,346	1	\$ 105,584
Mine Area Reclamation Materials	N/A	\$ 68,239.50	1	1	\$ 12,686
				Total	\$ 141,648
Haul Road Reclamation	Crew	Daily	Unit #	Days	Cost
Excavator 3.5 cy ~ 80K-100K lb.	B12D	\$ 3,664.00	1	7	\$ 25,648
Loader 5cy+	B10U	\$ 2,032.94	1	7	\$ 14,231
Dozer D6	B10M	\$ 2,931.70	1	7	\$ 20,522
Grader 30,000 lb.	B11L	\$ 2,413.50	1	7	\$ 16,895
Off Road Haul Truck	B34F	\$ 1,653.82	2	7	\$ 23,153
Haul Road Reclamation Materials	N/A	\$ 21,225.60	1	1	\$ 21,226
				Total	\$ 121,674

**Table E-21. Brodie 1 Mine, Cost Estimate Details for Alternative 4,
Off-Navajo Nation Disposal at White Mesa Mill**

Contractor Site Overhead	Crew	Unit	Amount	Price	Cost
Project Manager (10% of time)	N/A	Hour	19	\$ 175	\$ 3,263
Site Superintendent	N/A	Hour	186	\$ 191	\$ 35,609
H&S Officer	N/A	Hour	186	\$ 85	\$ 15,847
QA/QC Officer	N/A	Hour	186	\$ 85	\$ 15,847
Field Clerk	N/A	Hour	186	\$ 19	\$ 3,542
Fuel for Site Vehicles	N/A	Month	5	\$ 1,600	\$ 8,452
Port-o-let Rental (4)	N/A	Month	4	\$ 208	\$ 776
Permanent Fencing Installation and Demolition	N/A	LF	567	\$ 41.92	\$ 23,787
Job Trailers (1)	N/A	Month	1	\$ 269	\$ 251
Storage Boxes (1)	N/A	Month	1	\$ 95	\$ 88
Field Office Lights/HVAC (1)	N/A	Month	1	\$ 179	\$ 167
Generator (1)	N/A	Month	2	\$ 2,400	\$ 4,474
Fuel for Generator	N/A	Gallons	559	\$ 4	\$ 2,237
Telephone/internet (1)	N/A	Month	1	\$ 384	\$ 358
Field Office Equipment	N/A	Month	1	\$ 230	\$ 214
Field Office Supplies	N/A	Month	1	\$ 96	\$ 89
Trash (1 dumpster)	N/A	Month	1	\$ 910	\$ 848
Clin 1034 High Volume Air Sampling (4)	N/A	Month	4	\$ 383	\$ 1,428
Clin 1025 Ludlum 2121 and 43-10-1	N/A	Month	1	\$ 275	\$ 256
Air Monitoring Lab Confirmation Sampling (5 samples per day)	N/A	Day	93	\$ 600	\$ 55,931
Clin 1036 Personal Air Monitor	N/A	Month	7	\$ 204	\$ 1,346
Clin 1038 Personal Dust Monitor	N/A	Month	7	\$ 1,555	\$ 10,263
Clin 1068 Personal Dosimeter Badge	N/A	Month	7	\$ 59	\$ 389
Truck Scales	N/A	Month	1	\$ 300	\$ 280
Construction Water (excavation)	N/A	Gallon	3,079	\$ 0.05	\$ 154
Construction Water (hauling waste soil plus cap mat'l)	N/A	Gallon	62,994	\$ 0.05	\$ 3,150
6,000 Gallon Water Truck and Operator (1)	N/A	Day	19	\$ 889	\$ 16,574
Portal Water Tower Trailer, 10,000 gallons (1)	N/A	Day	19	\$ 172.36	\$ 3,213
					\$ 208,834
Third-Party Oversight	Crew	Unit	Amount	Price	Cost
Travel and Lodging (4 people)	N/A	Day	75	\$ 151	\$ 11,261
Labor	N/A	Hour	746	\$ 80	\$ 59,659
Car Rental (4 cars)	N/A	Month	4	\$ 400	\$ 1,491
Car Fuel	N/A	Month	4	\$ 760	\$ 2,834
					\$ 75,245
Level of Accuracy (20%)	Crew	Unit	Amount	Price	Cost
20% of Construction Cost	N/A	N/A	N/A	N/A	\$ 76,139
Navajo Tax (6%)	Crew	Unit	Amount	Price	Cost
6% of Confirmation Sampling, Construction, Contractor Overhead, Mobilization / Demobilization, and Third Party Oversight Costs	N/A	N/A	N/A	N/A	\$ 58,277
			GRAND TOTAL		\$ 1,888,299

**Table E-21. Brodie 1 Mine, Cost Estimate Details for Alternative 4,
Off-Navajo Nation Disposal at White Mesa Mill**

PRSC Costs	Crew	Unit	Amount	Price	Cost
Bi-annual Inspection (4 person crew, 1 day, 10 hr/day)	N/A	Hour	80	\$ 85.00	\$ 6,800
Mileage (Farmington, NM, to Site, roundtrip)	N/A	Mile	217	\$ 0.58	\$ 126
Inspection Crew Per Diem	N/A	Day	8	\$ 151.00	\$ 1,208
Assumed Annual Maintenance costs (revegetation, grading, watering)	N/A	SY	2,236	\$ 1.11	\$ 2,484
Preperation of Semi-annual Reports (Professional Engineer)	N/A	Hour	80	\$ 120.00	\$ 9,600
PRSC Annual Cost					\$ 20,218
PRSC Contingency (15%)					\$ 3,033
Navajo Tax (6% of PRSC and Contingencies Cost					\$ 1,395
Total PRSC Annual Cost					\$ 24,646

Notes:

"	Inch
CAD	Computer-aided design
CY	Cubic yard
GIS	Geographic information system
H&S	Health and safety
hp	Horsepower
hr	Hour
HVAC	Heating, ventilation, and air conditioning
K	Thousand
lb.	Pound
LF	Linear feet
LiDAR	Light detection and ranging
LS	Lump sum
M2	Square meters
N/A	Not applicable
NM	New Mexico
PRSC	Post-removal site control
QA/QC	Quality assurance/quality control
SY	Square yard
XRF	X-ray fluorescence

**Table E-22. Brodie 1 Mine, Cost Estimate Summary for Alternative 4,
Off-Navajo Nation Disposal at White Mesa Mill**

Waste Volume	1,310 CY
Removal Area	0.22 AC
Haul Road Building	Ratio T&M Cost
Excavator 3.5 cy ~ 80K-100K lb.	\$ 14,656
Dozer D6	\$ 11,727
Grader 30,000 lb.	\$ 9,654
Water Truck	\$ 3,556
Off Road Haul Truck	\$ 26,461
Rip Rap Class II 18"-24"	\$ 18,878
Subtotals Step 1	\$ 84,931
Excavation & Hauling	Unit Cost
Loader 5cy+	\$ 8,132
Off Road Haul Truck	\$ -
Grader 30,000 lb.	\$ 9,654
Excavator 3.5 cy ~ 80K-100K lb.	\$ 14,656
Subtotals Step 2	\$ 32,442
Reclamation	Unit Cost
Off Road Haul Truck	\$ 9,923
Loader 5cy+	\$ 2,033
Grader 30,000 lb.	\$ 4,827
Excavator 3.5 cy ~ 80K-100K lb.	\$ 3,664
Dozer D6	\$ 2,932
Rip Rap Class II 18"-24"	\$ 105,584
Mine Area Reclamation Materials	\$ 12,686
Subtotals Step 3	\$ 141,648
Haul Road Reclamation	Unit Cost
Excavator 3.5 cy ~ 80K-100K lb.	\$ 25,648
Loader 5cy+	\$ 14,231
Dozer D6	\$ 20,522
Grader 30,000 lb.	\$ 16,895
Off Road Haul Truck	\$ 23,153
Haul Road Reclamation Materials	\$ 21,226
Subtotals Step 4	\$ 121,674
Subtotal Construction	\$ 380,696
Other Costs	Unit Cost
Non-Construction Costs	
Engineering Design	\$ 320,689
Planning Documents	\$ 315,294
Resource Surveys	\$ 18,933
Confirmation Sampling	\$ 182,179
Reporting	\$ 158,033
Contractor Site Overhead	\$ 208,834
Mobilization / Demobilization	\$ 48,190
Travel+ Lodging (Construction Workers)	\$ 45,790
Level of Accuracy (20%)	\$ 76,139
Third-Party Oversight	\$ 75,245
Navajo Tax (6%)	\$ 58,277

**Table E-22. Brodie 1 Mine, Cost Estimate Summary for Alternative 4,
Off-Navajo Nation Disposal at White Mesa Mill**

Subtotals Step 6	\$ 1,507,603
Total Site Capital Costs	\$ 1,888,299
Yearly On-Site PRSC Costs	Unit Cost
Bi-annual Inspection (4 person crew, 3 days, 10 hr/day)	\$ 6,800
Mileage (Farmington, NM, to Site, roundtrip)	\$ 126
Inspection Crew Per Diem	\$ 1,208
Assumed Annual Maintenance costs (revegetation, grading, watering)	\$ 2,484
Preperation of Semi-annual Reports (Professional Engineer)	\$ 9,600
Subtotal PRSC Costs	\$ 20,218
PRSC Contingencies (15%)	\$ 3,033
Navajo Tax (6% of PRSC and Contingencies Cost)	\$ 1,395
Total Yearly PRSC Costs	\$ 24,646
Present Value of PRSC Costs Based on 10-Year Life at 3.50% (PV Factor = 8.317)	\$ 204,983
Waste Hauling Cost	
Waste Hauling Cost per CY	\$ 23
Waste Hauling Total Cost	\$ 37,139
White Mesa Milling and Disposal Cost	
White Mesa Milling and Disposal Cost per CY	\$ 81
White Mesa Milling and Disposal Cost	\$ 132,638
Grand Total Capital Costs	\$ 2,058,075
TOTAL COSTS	\$ 2,263,058

Notes:

"

AC

CY

ET

hp

hr

K

lb.

LF

NM

PRSC

PV

T&M

Inch

Acres

Cubic yard

Evapotranspiration

Horsepower

Hour

Thousand

Pound

Linear feet

New Mexico

Post-removal site control

Present value

Time and material

**Table E-23. Brodie 1 Mine, Cost Estimate Scenario Assumptions for Alternative 5,
Off-Navajo Nation Disposal at Clean Harbors RCRA C Hazardous Waste Disposal Facility**

Technology	Assumptions	Cost Effects
Excavation Methods	Waste removed by an excavator is assumed to be removed with a large excavator, unless specified	Excavators can operate on steeper terrain than bulldozers and are better at moving waste uphill. Bulldozers cost less to operate. Spider excavators or other specialized equipment are more expensive.
	Any disturbed surface can be restored using grading and erosion controls	Quantities of erosion control materials and grading may be lower than costed
	Land is barren to warrant no clearing or grubbing	Costs of clearing and grubbing are zero
	All waste specified in the risk assessment will be excavated	Volumes of excavated waste may be lower than costed
	The site is accessible to haul trucks and trucks can be easily loaded	Accessing difficult-to-reach mines increase costs.
Soil and Waste Sorting	Mine waste will be sorted based on grain size; rock greater than 3 inches will be segregated	NA
Hazardous Waste Landfill or Licensed Low-Level Radioactive Waste Facility	Landfill location is available within 450 road miles of the mine waste	Greater distance to repository increases costs.
	Waste can go to Deer Trail, Colorado (565 miles); Andrews, Texas (618 miles); or Clive, Utah (450 miles).	Waste will go to the closest facility that is accepting waste, Deer Trail, Colorado
	Waste will be transported 565 miles in highway-legal trucks from the mine site to the disposal facility in Deer Trail, Colorado	Greater distance to repository increases costs
	Cycle time limited to 25 trucks every three days, due to space. Assumes maximum number of trucks (25) for fastest production rate.	Less trucks will reduce production time and require more time on-site, increasing costs.
	Waste weighs 1.5 tons per cubic yard	Higher density waste will increase costs
	Tipping fee (\$/CY)	Higher tipping fee results in increased costs; current tipping fees are from previous cost estimate
	PRSC inspection of the mine site will be completed for 10 years	More PRSC inspections will increase costs
	The waste excavation area will not require cover soil or amendment	If cover soil or amendments are required, costs will increase

Notes:

CY	Cubic yard
ET	Evapotranspiration
GCL	Geosynthetic clay liner
NA	Not applicable - inherent assumption
PRSC	Post-removal site control

**Table E-24. Brodie 1 Mine, Crew Time Productivity Calculations for Alternative 5,
Off-Navajo Nation Disposal at Clean Harbors RCRA C Hazardous Waste Disposal Facility**

	Waste Volume	1,310	CY		
	Removal Area	0.22	AC		
Step	Brodie 1 Haul Road Installation				
1	Action	QTY	Unit	Production CY	Days
	Brodie 1 Lower Haul Road - Excavation	2,875	LCY	1,531	1.9
	Brodie 1 Upper Access Road - Excavation	1,760	LCY	1,531	1.15
	Rock Fields	155	CY	2,652	0.06
				Control Days	3
Step	Brodie 1 Excavation				
2	Action	QTY	Unit	Production CY	Days
	Waste Removal WP M1 and Excavate Drainage - Excavator	1,638	LCY	140	11.7
		1,638		Control Days	11.7
Step	Brodie 1 Restoration				
3	Action	QTY	Unit	Production Rate	Days
	Clean Borrow Fill	807	CY	5,304	0.2
	Grading	2,236	SY	1.3 Days for 2,222 SY	1.3
	Fertilizer, Seed, Mulch	2,236	SY	1,000	2.2
	Erosion Control - Erosion Control Blanket	980	SY	1,000	1.0
	Erosion Control - Coir Logs/Wattles	240	LF	1,000	0.2
	Gabion Weir	0	SY	60	0.0
	Rock Berms	219	LCY	3,864	0.5
	Rock Fields	650	CY	5,304	0.12
				Control Days	6
Step	Brodie 1 Haul Road Restoration				
4	Action	QTY	Unit	Production Rate	Days
	Fertilizer, Seed, Mulch	5,280	SY	1,000	5
	Haul Road Reclamation - Haul Fill	4,635	LCY	5,304	0.9
				Control Days	6
				TOTAL PROJECT DAYS	26
				Slowest Rate Project Days:	26

Notes:

AC
 BCY Bank cubic yard
 CY Cubic yard
 LCY Loose cubic yard
 LF Linear foot
 Mi Mile
 QTY Quantity
 SY Square yard

Table E-25. Brodie 1 Mine, Equipment Cost Details for Alternative 5, Off-Navajo Nation Disposal at Clean Harbors RCRA C Hazardous Waste Disposal Facility

Step	Equipment List	QTY	RSMeans #	RSMeans Description	Unit Cost	Unit	Crew
1	M1 Haul Road Building						
	Excavator 3.5 CY ~ 80K-100K lb.	1	312316420305	3.5 CY Excavator Capacity = 300 CY/hour	\$ 1.78	BCY	B12D
	Dozer D6	1	312213200170	8,100-10,000 SF Grading, Dozer	\$ 1,378.08	each	B10L
			015433204260	Rent Dozer, crawler, torque converter, diesel 200 hp	\$ 15,960	Month	None (Rental)
	Grader 30,000 lb.	1	340113100310	Maintenance grading of roadway, 4 passes, 3.0 MPH	\$ 631.65	Mile	B11L
			015433201910	Rent Grader, Self Propelled, 30,000 lb.	\$ 12,705	Month	None (Rental)
	Off-Road Haul Truck	4	312323205110	22 CY, 5 MPH, 15 min wait/lb./unlb, 2-mile cycle	\$ 6.32	LCY	B34F
2	M1 Excavation						
	Off-Road Haul Truck	2	312323205110	22 CY, 5 MPH, 15 min wait/lb./unlb, 2-mile cycle	\$ 6.32	LCY	B34F
	Loader 5cy+	1	312323154080	Common Earth - 5cy bucket, front end loader	\$ 16.30	BCY	B10U
			015433204760	Rent front end loader, articulating, 5.25-5.75 CY 270 HP	\$ 8,478.75	Month	None (Rental)
	Grader 30,000 lb.	1	340113100310	Maintenance grading of roadway, 4 passes, 3.0 MPH	\$ 631.65	Mile	B11L
			015433201910	Rent Grader, Self Propelled, 30,000 lb.	\$ 12,705	Month	None (Rental)
	Excavator 3.5 CY ~ 80K-100K lb.	1	312316420305	3.5 CY Excavator Capacity=300 CY/hour	\$ 1.78	BCY	B12D
3	M1 Reclamation						
	Off-Road Haul Truck	1	312323205110	22 CY, 5 MPH, 15 min wait/lb./unlb, 2-mile cycle	\$ 6.32	LCY	B34F
	Loader 5CY+	1	312323154080	Common Earth - 5 CY bucket, front-end loader	\$ 16.30	BCY	B10U
			015433204760	Rent front-end loader, articulating, 5.25-5.75 CY 270 hp	\$ 8,478.75	Month	None (Rental)
	Dozer D6	1	312213200170	8,100-10,000 SF Grading, Dozer	\$ 1,378.08	each	B10L
			015433204260	Rent Dozer, crawler, torque converter, diesel 200 hp	\$ 15,960	Month	None (Rental)

**Table E-25. Brodie 1 Mine, Equipment Cost Details for Alternative 5, Off-Navajo Nation Disposal at Clean Harbors RCRA C
Hazardous Waste Disposal Facility**

	Grader 30,000 lb.	1	340113100310	Maintenance grading of roadway, 4 passes, 3.0 MPH	\$ 631.65	Mile	B11L
			015433201910	Rent Grader, Self Propelled, 30,000 lb.	\$ 12,705	Month	None (Rental)
	Excavator 3.5 CY ~ 80K-100K lb.	1	312316420305	3.5 CY Excavator Capacity = 300 CY/hour	\$ 1.78	BCY	B12D
	Rip Rap Class II 18"-24"	2346		Assume \$5/mile Class II within 115 miles =	\$ 45.00	Ton	
4	M1 Haul Road Closure						
	Excavator 3.5 CY ~ 80K-100K lb.	1	312316420305	3.5 CY Excavator Capacity = 300 CY/hour	\$ 1.78	BCY	B12D
	Loader 5CY+	1	312323154080	Common Earth - 5 CY bucket, front-end loader	\$ 16.30	BCY	B10U
			015433204760	Rent front-end loader, articulating, 5.25-5.75 CY 270 hp	\$ 8,478.75	Month	None (Rental)
	Dozer D6	1	312213200170	8,100-10,000 SF Grading, Dozer	\$ 1,378.08	each	B10L
			015433204260	Rent Dozer, crawler, torque converter, diesel 200 hp	\$ 15,960	Month	None (Rental)
	Grader 30,000 lb.	1	340113100310	Maintenance grading of roadway, 4 passes, 3.0 MPH	\$ 631.65	Mile	B11L
			015433201910	Rent Grader, Self Propelled, 30,000 lb.	\$ 12,705	Month	None (Rental)
	Off-Road Haul Truck	1	312323205110	22 CY, 5 MPH, 15 min wait/ld./unld, 2-mile cycle	\$ 6.32	LCY	B34F

Notes:

' Foot
 " Inch
 BCY Bank cubic yard
 CY Cubic yard
 hp Horse power
 K Thousand
 lb. Pound
 LCY Loose cubic yard
 ld. Loaded
 LF Linear foot
 M2 Square meters
 MPH Mile per hour
 psi Pound per square inch
 QTY Quantity
 SF Square feet
 unld. Unloaded
 W Width

Table E-26. Brodie 1 Mine, Cost Estimate Details for Alternative 5, Off-Navajo Nation Disposal at Clean Harbors RCRA C Hazardous Waste Disposal Facility

Engineering Design	Crew	Unit	Amount	Price	Cost
Project Manager	N/A	Hour	293	\$ 158.00	\$ 46,294
Project Engineer	N/A	Hour	1,170	\$ 122.00	\$ 142,740
Design Engineer	N/A	Hour	585	\$ 158.00	\$ 92,430
CAD/GIS Operator	N/A	Hour	293	\$ 102.00	\$ 29,886
Admin	N/A	Hour	117	\$ 67.00	\$ 7,839
Reproduction	N/A	LS	3	\$ 500.00	\$ 1,500
					\$ 320,689
Planning Documents	Crew	Unit	Amount	Price	Cost
Project Manager	N/A	Hour	405	\$ 158.00	\$ 63,990
Project Engineer	N/A	Hour	1,620	\$ 122.00	\$ 197,640
CAD/GIS Operator	N/A	Hour	405	\$ 102.00	\$ 41,310
Admin	N/A	Hour	162	\$ 67.00	\$ 10,854
Reproduction	N/A	LS	3	\$ 500.00	\$ 1,500
					\$ 315,294
Resource Surveys	Crew	Unit	Amount	Price	Cost
Cultural Resources Mitigation	N/A	Each	1	\$ 2,366.64	\$ 2,367
Biological Resources Mitigation	N/A	Each	1	\$ 4,733.28	\$ 4,733
Geotechnical Testing and Report	N/A	Each	1	\$ 4,733.28	\$ 4,733
Pre-Project Aerial LIDAR Survey	N/A	Each	0	\$ 30,000.00	\$ -
Post-Project Aerial LiDAR Survey	N/A	Each	1	\$ 7,099.92	\$ 7,100
					\$ 18,933
Confirmation Sampling	Crew	Unit	Amount	Price	Cost
Developing Sampling and Analysis Plan					
Project Geologist	N/A	Hour	360	\$ 158.00	\$ 56,880
Project Manager	N/A	Hour	180	\$ 111.00	\$ 19,980
CAD/GIS Operator	N/A	Hour	180	\$ 122.00	\$ 21,960
Project Chemist	N/A	Hour	360	\$ 111.00	\$ 39,960
Health and Safety Manager	N/A	Hour	180	\$ 151.00	\$ 27,180
Admin	N/A	Hour	72	\$ 67.00	\$ 4,824
Reproduction	N/A	LS	3	\$ 250.00	\$ 750
Sampling					
Sampling Team - Staff Geologist	N/A	Hour	7	\$ 77.00	\$ 547
Sampling Team - Staff Engineer	N/A	Hour	7	\$ 81.00	\$ 575
Travel	N/A	Day	2	\$ 170.00	\$ 340
Per Diem (96/55)	N/A	Day	2	\$ 151.00	\$ 302
Miscellaneous Field Supplies and Expenses	N/A	LS	1	\$ 1,209.83	\$ 1,210
Lab Analysis	N/A	LS	1	\$ 389.79	\$ 390
XRF Surveying					
Sampling Team - Staff Geologist	N/A	Hour	27	\$ 77.00	\$ 2,041
Sampling Team - Staff Engineer	N/A	Hour	27	\$ 81.00	\$ 2,147
Travel	N/A	Day	3	\$ 170.00	\$ 510
Per Diem (96/55)	N/A	Day	4	\$ 151.00	\$ 643
Miscellaneous Field Supplies and Expenses	N/A	LS	1	\$ 1,209.83	\$ 1,210
Lab Analysis	N/A	LS	1	\$ 389.79	\$ 390
Frisking Equipment	N/A	Month	2	\$ 144.00	\$ 341
					\$ 182,179

Table E-26. Brodie 1 Mine, Cost Estimate Details for Alternative 5, Off-Navajo Nation Disposal at Clean Harbors RCRA C Hazardous Waste Disposal Facility

Reporting	Crew	Unit	Amount	Price	Cost
Project Geologist	N/A	Hour	316	\$ 105.00	\$ 33,180
Project Manager	N/A	Hour	158	\$ 175.00	\$ 27,650
Project Engineer	N/A	Hour	474	\$ 122.00	\$ 57,828
Chemist	N/A	Hour	158	\$ 111.00	\$ 17,538
CAD/GIS Operator	N/A	Hour	158	\$ 102.00	\$ 16,116
Admin	N/A	Hour	63	\$ 67.00	\$ 4,221
Reproduction	N/A	LS	3	\$ 500.00	\$ 1,500
					\$ 158,033
Mobilization/Demobilization	Crew	Unit	Amount	Price	Cost
Crew Mileage	N/A	Mile	5,040	\$ 0.56	\$ 2,822
Per Diem	N/A	Day	15	\$ 182.00	\$ 2,730
Labor	N/A	Day	15	\$ 300.00	\$ 4,500
Standard Equipment Mileage	N/A	Mile	5,040	\$ 0.56	\$ 2,822
Standard Equipment Rental	N/A	Day	2	\$ 17,657.42	\$ 35,315
					\$ 48,190
Haul Road Building	Crew	Daily	Unit #	Days	Cost
Excavator 3.5 cy ~ 80K-100K lb.	B12D	\$ 3,664.00	1	4	\$ 14,656
Dozer D6	B10M	\$ 2,931.70	1	4	\$ 11,727
Grader 30,000 lb.	B11L	\$ 2,413.50	1	4	\$ 9,654
Water Truck	B45	\$ 889.00	1	4	\$ 3,556
Off Road Haul Truck	B34F	\$ 1,653.82	4	4	\$ 26,461
Rip Rap Class II 18"-24"	NA	\$ 45.00	419.5	1	\$ 18,878
				Total	\$ 84,931
Excavation & Hauling	Crew	Daily	Unit #	Days	Cost
Loader 5cy+	B10U	\$ 2,032.94	1	12	\$ 24,395
Off Road Haul Truck	B34F	\$ 1,653.82	0	12	\$ -
Grader 30,000 lb.	B11L	\$ 2,413.50	1	12	\$ 28,962
Excavator 3.5 cy ~ 80K-100K lb.	B12D	\$ 3,664.00	1	12	\$ 43,968
				Total	\$ 97,325
Reclamation	Crew	Daily	Unit #	Days	Cost
Off Road Haul Truck	B34F	\$ 1,653.82	1	6	\$ 9,923
Loader 5cy+	B10U	\$ 2,032.94	1	1	\$ 2,033
Grader 30,000 lb.	B11L	\$ 2,413.50	1	2	\$ 4,827
Excavator 3.5 cy ~ 80K-100K lb.	B12D	\$ 3,664.00	1	1	\$ 3,664
Dozer D6	B10M	\$ 2,931.70	1	1	\$ 2,932
Rip Rap Class II 18"-24"	NA	\$ 45.00	2,346	1	\$ 105,584
Mine Area Reclamation Materials	N/A	\$ 68,239.50	1	1	\$ 12,686
				Total	\$ 141,648
Haul Road Reclamation	Crew	Daily	Unit #	Days	Cost
Excavator 3.5 cy ~ 80K-100K lb.	B12D	\$ 3,664.00	1	7	\$ 25,648
Loader 5cy+	B10U	\$ 2,032.94	1	7	\$ 14,231
Dozer D6	B10M	\$ 2,931.70	1	7	\$ 20,522
Grader 30,000 lb.	B11L	\$ 2,413.50	1	7	\$ 16,895
Off Road Haul Truck	B34F	\$ 1,653.82	2	7	\$ 23,153
Haul Road Reclamation Materials	N/A	\$ 21,225.60	1	1	\$ 21,226
				Total	\$ 121,674

Table E-26. Brodie 1 Mine, Cost Estimate Details for Alternative 5, Off-Navajo Nation Disposal at Clean Harbors RCRA C Hazardous Waste Disposal Facility

Contractor Site Overhead	Crew	Unit	Amount	Price	Cost
Project Manager (10% of time)	N/A	Hour	26	\$ 175.00	\$ 4,631
Site Superintendent	N/A	Hour	265	\$ 191.00	\$ 50,545
H&S Officer	N/A	Hour	265	\$ 85.00	\$ 22,494
QA/QC Officer	N/A	Hour	265	\$ 85.00	\$ 22,494
Field Clerk	N/A	Hour	265	\$ 19.00	\$ 5,028
Fuel for Site Vehicles	N/A	Month	7	\$ 1,600.00	\$ 11,997
Port-o-let Rental (4)	N/A	Month	5	\$ 208.00	\$ 1,101
Permanent Fencing Installation and Demolition	N/A	LF	567	\$ 41.92	\$ 23,787
Job Trailers (1)	N/A	Month	1	\$ 269.00	\$ 356
Storage Boxes (1)	N/A	Month	1	\$ 94.50	\$ 125
Field Office Lights/HVAC (1)	N/A	Month	1	\$ 179.00	\$ 237
Generator (1)	N/A	Month	3	\$ 2,400.00	\$ 6,351
Fuel for Generator	N/A	Gallons	794	\$ 4.00	\$ 3,176
Telephone/internet (1)	N/A	Month	1	\$ 384.00	\$ 508
Field Office Equipment	N/A	Month	1	\$ 230.00	\$ 304
Field Office Supplies	N/A	Month	1	\$ 96.00	\$ 127
Trash (1 dumpster)	N/A	Month	1	\$ 910.00	\$ 1,204
Clin 1034 High Volume Air Sampling (4)	N/A	Month	5	\$ 383.00	\$ 2,027
Clin 1025 Ludlum 2121 and 43-10-1	N/A	Month	1	\$ 275.00	\$ 364
Air Monitoring Lab Confirmation Sampling (5 samples per day)	N/A	Day	132	\$ 600.00	\$ 79,390
Clin 1036 Personal Air Monitor	N/A	Month	7	\$ 204.00	\$ 1,346
Clin 1038 Personal Dust Monitor	N/A	Month	7	\$ 1,555.00	\$ 10,263
Clin 1068 Personal Dosimeter Badge	N/A	Month	7	\$ 59.00	\$ 389
Truck Scales	N/A	Month	1	\$ 300.00	\$ 397
Construction Water (excavation)	N/A	Gallon	3,079	\$ 0.05	\$ 154
Construction Water (hauling waste soil plus cap mat'l)	N/A	Gallon	62,994	\$ 0.05	\$ 3,150
6,000 Gallon Water Truck and Operator (1)	N/A	Day	26	\$ 889.00	\$ 23,526
Portal Water Tower Trailer, 10,000 gallons (1)	N/A	Day	26	\$ 172.36	\$ 4,561
					\$ 280,032
Third-Party Oversight	Crew	Unit	Amount	Price	Cost
Travel and Lodging (4 people)	N/A	Day	106	\$ 151.00	\$ 15,984
Labor	N/A	Hour	1059	\$ 80.00	\$ 84,683
Car Rental (4 cars)	N/A	Month	5	\$ 400.00	\$ 2,117
Car Fuel	N/A	Month	5	\$ 760.00	\$ 4,022
					\$ 106,806
Level of Accuracy (20%)	Crew	Unit	Amount	Price	Cost
20% of Construction Cost	N/A	N/A	N/A	N/A	\$ 89,116
Navajo Tax (6%)	Crew	Unit	Amount	Price	Cost
6% of Confirmation Sampling, Construction, Contractor Overhead, Mobilization / Demobilization, and Third Party Oversight Costs	N/A	N/A	N/A	N/A	\$ 69,114
			GRAND TOTAL		\$ 2,093,099

Table E-26. Brodie 1 Mine, Cost Estimate Details for Alternative 5, Off-Navajo Nation Disposal at Clean Harbors RCRA C Hazardous Waste Disposal Facility

PRSC Costs	Crew	Unit	Amount	Price	Cost
Bi-annual Inspection (4 person crew, 1 day, 10 hr/day)	N/A	Hour	80	\$ 85.00	\$ 6,800
Mileage (Farmington, NM, to Site, roundtrip)	N/A	Mile	217	\$ 0.58	\$ 126
Inspection Crew Per Diem	N/A	Day	8	\$ 151.00	\$ 1,208
Assumed Annual Maintenance costs (revegetation, grading, watering)	N/A	SY	2,236	\$ 1.11	\$ 2,484
Preperation of Semi-annual Reports (Professional Engineer)	N/A	Hour	80	\$ 120.00	\$ 9,600
PRSC Annual Cost					\$ 20,218
PRSC Contingency (15%)					\$ 3,033
Navajo Tax (6% of PRSC and Contingencies Cost					\$ 1,395
Total PRSC Annual Cost					\$ 24,646
Road PRSC Costs (every 10 years)	Crew	Unit	Amount	Price	Cost
Mileage (Farmington, NM, to Site, roundtrip, 3 vehicles, 3 trips every 10 years)	N/A	Mile	224	\$ 0.06	\$ 13
Construction Crew Per Diem and Labor (9 people, 3 trips every 10 years, 2 extra days to mob/demob)	N/A	Day	2	\$ 433.80	\$ 895
Widen, Grade, Compact Equipment Rental Grader, Loader, Excavator, Dozer, Haul Truck	N/A	Day	2	\$ 1,221.76	\$ 2,521
Gravel (assumed 5% of total area, 750 tons per acre)	N/A	Ton	63.20	\$ 1.80	\$ 114
Riprap Class II (assume 3 tons per 1,000 LF of road)	N/A	Ton	13.77	\$ 5.50	\$ 76
PRSC Annual Cost					\$ 3,619
PRSC Contingency (15%)					\$ 543
Navajo Tax (6% of PRSC and Contingencies Cost					\$ 250
Total PRSC Annual Cost					\$ 4,412

Notes:

"	Inch
CAD	Computer-aided design
CY	Cubic yard
GIS	Geographic information system
H&S	Health and safety
hp	Horsepower
hr	Hour
HVAC	Heating, ventilation, and air conditioning
K	Thousand
lb.	Pound
LF	Linear feet
LiDAR	Light detection and ranging
LS	Lump sum
M2	Square meters
N/A	Not applicable
NM	New Mexico
PRSC	Post-removal site control
QA/QC	Quality assurance/quality control
SY	Square yard
XRF	X-ray fluorescence

**Table E-27. Brodie 1 Mine, Cost Estimate Summary for Alternative 5,
Off-Navajo Nation Disposal at Clean Harbors RCRA C Hazardous Waste Disposal Facility**

Waste Volume	1,310 CY
Removal Area	0.22 AC
Haul Road Building	Ratio T&M Cost
Excavator 3.5 cy ~ 80K-100K lb.	\$ 14,656
Dozer D6	\$ 11,727
Grader 30,000 lb.	\$ 9,654
Water Truck	\$ 3,556
Off Road Haul Truck	\$ 26,461
Rip Rap Class II 18"-24"	\$ 18,878
Subtotals Step 1	\$ 84,931
Excavation & Hauling	Unit Cost
Loader 5cy+	\$ 24,395
Off Road Haul Truck	\$ -
Grader 30,000 lb.	\$ 28,962
Excavator 3.5 cy ~ 80K-100K lb.	\$ 43,968
Subtotals Step 2	\$ 97,325
Reclamation	Unit Cost
Off Road Haul Truck	\$ 9,923
Loader 5cy+	\$ 2,033
Grader 30,000 lb.	\$ 4,827
Excavator 3.5 cy ~ 80K-100K lb.	\$ 3,664
Dozer D6	\$ 2,932
Rip Rap Class II 18"-24"	\$ 105,584
Mine Area Reclamation Materials	\$ 12,686
Subtotals Step 3	\$ 141,648
Haul Road Reclamation	Unit Cost
Excavator 3.5 cy ~ 80K-100K lb.	\$ 25,648
Loader 5cy+	\$ 14,231
Dozer D6	\$ 20,522
Grader 30,000 lb.	\$ 16,895
Off Road Haul Truck	\$ 23,153
Haul Road Reclamation Materials	\$ 21,226
Subtotals Step 4	\$ 121,674
Subtotal Construction	\$ 445,579
Other Costs	Unit Cost
Non-Construction Costs	
Engineering Design	\$ 320,689
Planning Documents	\$ 315,294
Resource Surveys	\$ 18,933
Confirmation Sampling	\$ 182,179
Reporting	\$ 158,033
Contractor Site Overhead	\$ 280,032
Mobilization / Demobilization	\$ 48,190
Travel+ Lodging (Construction Workers)	\$ 59,134
Level of Accuracy (20%)	\$ 89,116
Third-Party Oversight	\$ 106,806
Navajo Tax (6%)	\$ 69,114

**Table E-27. Brodie 1 Mine, Cost Estimate Summary for Alternative 5,
Off-Navajo Nation Disposal at Clean Harbors RCRA C Hazardous Waste Disposal Facility**

Subtotals Step 6	\$	1,647,520
Total Site Capital Costs	\$	2,093,099
Yearly On-Site PRSC Costs	Unit Cost	
Bi-annual Inspection (4 person crew, 3 days, 10 hr/day)	\$	6,800
Mileage (Farmington, NM, to Site, roundtrip)	\$	126
Inspection Crew Per Diem	\$	1,208
Assumed Annual Maintenance costs (revegetation, grading, watering)	\$	2,484
Preperation of Semi-annual Reports (Professional Engineer)	\$	9,600
Subtotal PRSC Costs	\$	20,218
PRSC Contingencies (15%)	\$	3,033
Navajo Tax (6% of PRSC and Contingencies Cost)	\$	1,395
Total Yearly PRSC Costs	\$	24,646
Present Value of PRSC Costs Based on 10-Year Life at 3.50% (PV Factor = 8.317)	\$	204,983
Waste Hauling Cost		
Waste Hauling Cost per CY	\$	203
Waste Hauling Total Cost	\$	332,085
LLRW Disposal Cost		
LLRW Disposal Cost per CY	\$	105
LLRW Disposal Cost	\$	171,938
Grand Total Capital Costs	\$	2,597,122
TOTAL COSTS	\$	2,802,105

Notes:

"

AC

CY

ET

hp

hr

K

lb.

LF

NM

PRSC

PV

T&M

Inch

Acres

Cubic yard

Evapotranspiration

Horsepower

Hour

Thousand

Pound

Linear feet

New Mexico

Post-removal site control

Present value

Time and material

APPENDIX F

GREENER CLEANUP ANALYSIS (*NOT INCLUDED IN DRAFT*)